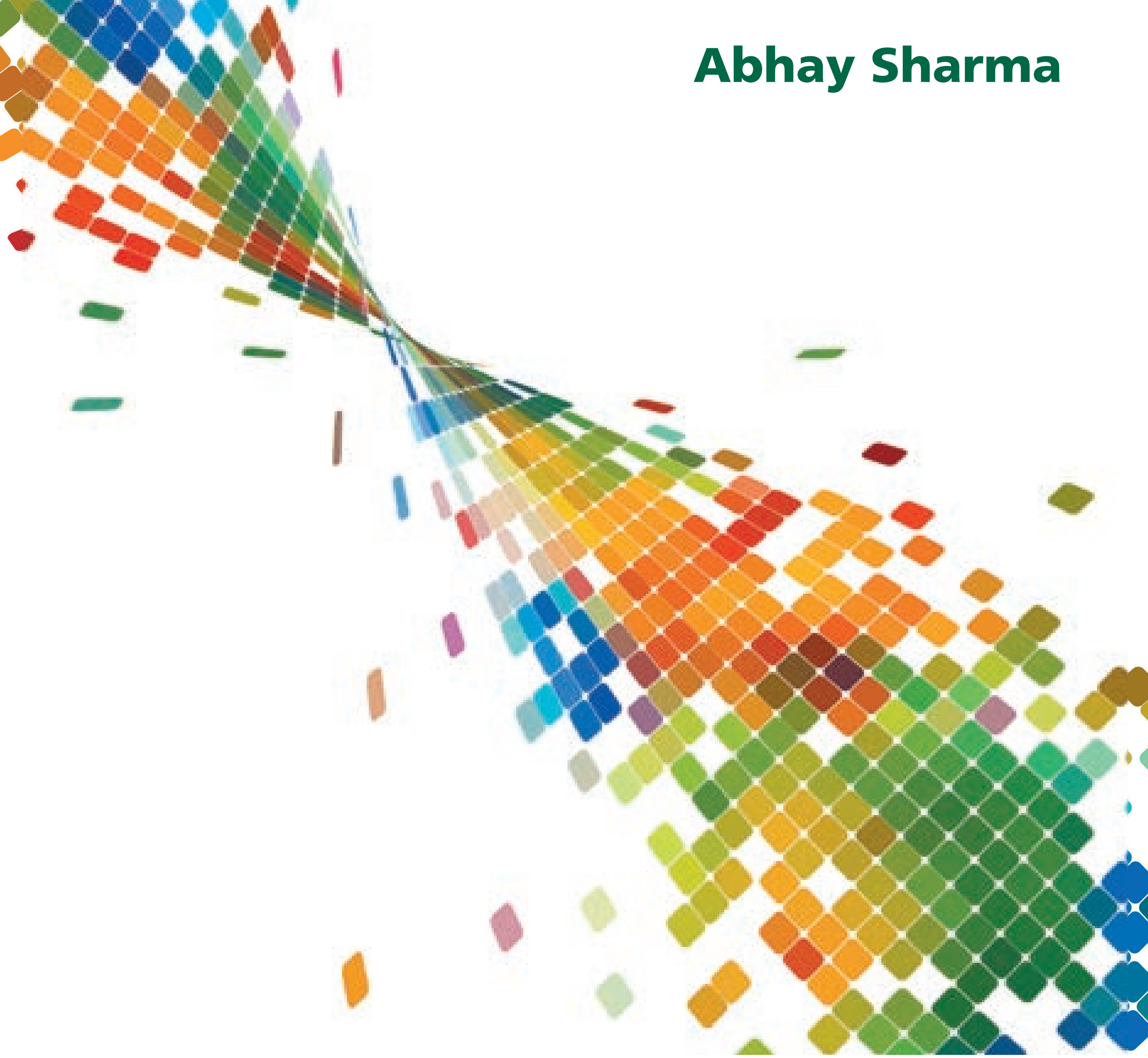
Abhay Sharma



UNDERSTANDING COLOR MANAGEMENT

Second Edition

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Understanding Color Management

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Understanding Color Management

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Second Edition

WILEY

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Dedicated to my daughter Sasha
Who is the color in my life

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Foreword to 2nd Edition

The first edition of *Understanding Color Management* established an accessible and practical introduction to the topic. Since the first edition was published much has changed in the color reproduction landscape. Many aspects have evolved – the technology used by industry, the expectations of customers, the scientific and technical understanding of users, and also the color management architecture and the ICC profile format. Users now have a more detailed understanding of the process. International standards – developed by ISO TC 130 Graphic Technology – have aided the industry to establish and maintain good practice. Workflow procedures, based largely on flavors of the PDF/X file format, have become more sophisticated and more reliable in delivering user expectations. Software applications used in color management have changed significantly, both the established workhorses and the specialist apps and tools. Research published in the main scientific and technical conferences and journals continues to advance our knowledge of the goals and requirements of color management. Color management could be said to have developed from a niche area to a stable and predictable part of the landscape. Yet, as old problems have been solved, new problems have emerged and we are a long way from making color completely "seamless between devices and documents", as the ICC aims to do.

The new edition keeps pace with these changes, and those familiar with the first edition will find a wealth of new material. The color science material has been updated, and the section on measurement instruments is substantially expanded to include material on topics such as repeatability and calibration and an explanation of the measurement modes standardized in ISO 13655. The ICC profile format is described in detail, with each of the main tag elements explained. The advantages of working with the v4 format, first introduced in 2001, are discussed and the latest ICC technology – iccMAX – is described.

Perhaps the core of the book, and the content that will be of most direct interest to readers, is a thorough description of practical color management for each of the main types of color device – cameras, displays and printers. The key topics that have been discussed by the industry for the last decade or so are reviewed and detailed context provided, and the reader is also shown how to make color management work and achieve good quality consistent reproduction.

The strength of this edition is its unique combination of accessible yet thorough description of the context for graphic arts color management, and practical guidelines on how to implement it. As a former Working Group chair in ICC, and a current representative of Ryerson University within ICC, Dr Sharma is in a good position to appreciate the complexities of the color management and its use today. He has done an excellent job of conveying the essentials to the reader.

Dr Phil Green
Norwegian University of Science and Technology, Gjøvik, Norway
ICC Technical Secretary
2017

Foreword to 1st Edition

Color management allows users to control and adjust color when images are reproduced on different devices and media. Thus, its importance grows in many industries. The explosion in the volume of color reproduction, and, more importantly, the number of people actually reproducing color images in a variety of media, is one, but not the only, reason for its importance.

The increasing demand to simplify color-reproduction processes will certainly make those processes more available, with minimal training, to those who need them. It will also increase productivity and automation in industries with color reproduction experience, such as printing and publishing. Traditional methods of color reproduction, which required some degree of skill to achieve high quality, have not been completely replaced – and probably never will be. However, relatively unskilled users can significantly improve the quality of reproduction by applying color management. Likewise, the productivity of skilled users can be significantly enhanced.

Unfortunately, color management is not a trivial subject to understand. Color management is usually based on profiles that conform to the internationally accepted ICC profile specification. Therefore, it relies on fairly advanced color science and imaging concepts. Furthermore, it depends on understanding how to control the various devices involved in color reproduction. This makes it difficult for an unskilled person who wishes to understand how color management works (and what to do if it seems to go wrong) to easily find the necessary information. Various papers can be found on the topic (such as on the ICC web site), but such papers either superficially cover the topic, or only cover a specific aspect.

For those without the color science and imaging skills, more is required if they want to understand the subject enough to decide what is needed in order to improve their color-reproduction quality and consistency.

This book presents a fairly complex subject in a way understandable to those looking for a sound introduction to the subject. It should appeal to students and those working casually or professionally in color reproduction. The introduction to the "science" of color reproduction is not overly complex, and the discussion on its practice is practical. Useful hints on resolving problems are included. As such, the book will be valuable to all new users and to those who wish to extend their knowledge by investigating the theory of color science and imaging in depth. Having spent over thirty years in this work, I consider color reproduction fascinating and recommend it as an enjoyable career. This book will provide an excellent first step along that path.

Tony Johnson
London College of Printing, London, England
ICC Technical Secretary
2004

Preface

There has been a huge increase in the use of color and in the number and range of devices used to produce color. There is now widespread use of digital cameras, flatpanel displays, inkjet printers, and Photoshop-type image editing software. Smartphones are able to capture high-resolution images. In commercial printing, a number of changes have occurred; instead of using a traditional proofer, such as a Kodak Approval, pages may now be proofed on an inkjet printer or may even be proofed on a monitor, with no hardcopy.

The exponential growth of affordable and good quality color imaging devices means that color imaging is now within reach of the average user, indeed we may say that color has been "democratized". We are now all responsible for our own color management which creates the need for some type of user-friendly, non-proprietary, framework for color control. A unified approach, supported by all vendors, is provided by the International Color Consortium (ICC). The ICC organization is color management's governing body. This book is all about "ICC color management".

Color management is a way of controlling color in digital imaging using software, hardware, and systematic procedures. Despite being around for a number of years, color management is confusing to many users. An air of mystery surrounds this topic; many of us are not sure what color settings to use and what all the different color management terms mean. We waste a lot of time and materials trying to get the color right. Color is often one of the most frustrating and annoying aspects of digital imaging.

The aim of *Understanding Color Management* is to present simply, but comprehensively, an introduction to color management, so as to promote the understanding and correct use of this technology. This book provides a well illustrated, definitive source of information for all those looking to make and use profiles for digital cameras and monitors, and to understand color management for printing and proofing. The text provides sufficient technical and theoretical explanations to enable you to understand the principles of color and create successful color management workflows.

Color management has a number of time and cost-saving benefits. This textbook explains the principles and practical aspects of this indispensable technology. Once you understand how color management works, you cannot fail to be impressed – and you will not go back to the old way of working!

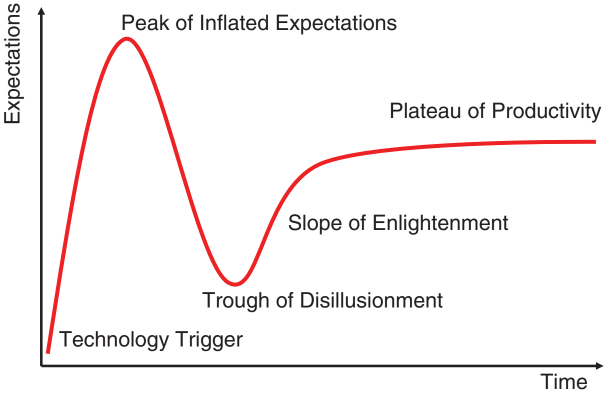

Figure 1 Color management evolution can be tracked using the Gartner Hype Cycle for technology innovation.

The Time is Right for Color Management

Color management has had a checkered history, as shown in Figure 1. At trade shows in the early 2000s, every vendor was flaunting a color management solution, at that time the technology was not ready for prime-time and there were many "*inflated expectations*".

In terms of the Gartner Hype Cycle, Figure 1, early proof-of-concept stories and media interest triggered significant publicity. Often no usable products existed and commercial viability was unproven. In the early days it was not clear how color management should be used. The problems and their solutions were not well defined. The technology was in its infancy and vendors, equipment manufacturers, and users were experimenting with different approaches and configurations. Many early products had interfaces that were complicated and non-intuitive. Because of this, the early process was complicated and the results were often poor and unpredictable.

Following the period of inflated expectations, there followed a "*trough of disillusionment*". This was a very dark time for color management. Color management products and processes got a bad name, and there was a general feeling that color management did not work and was too complicated for general use.

During the period referred to as the "*slope of enlightenment*" users realized that for color management to work there is the need to establish some standard operating procedures, to measure and monitor, and to install measuring equipment and tracking software. There is also the need to educate and train the workforce. Slowly, color management regained its status.

Following a reality-check, today's color management has reached a stable "*plateau of productivity*". There are now realistic expectations for color management; there is a clear understanding of what color management can and cannot do. Color management cannot achieve perfection, but it can get us very close quickly and consistently. Note that the level of the *plateau of productivity* (that represents the current state of the industry) is much lower than the initial high peak of over-inflated expectations. We observe that the level of the current plateau is lower, but is realistic and achievable.

The plateau is indicative of the current generation of color management products that are truly market-ready solutions. Developments and improvements are still being made, but we have reached a stage where color management provides a stable, credible solution. Color management systems and software have been evolving, growing into new areas such as spectral color processing or expanded gamut printing, however, the fundamental framework remains unchanged. We can say that recent changes in color management have been *evolutionary* and not *revolutionary*, as we move along the plateau.

Today we have an enormous improvement in software quality and usability, cheaper and better instruments, better compatibility between software and hardware, and better integration across the whole prepress-imaging industry. The technology has matured, users are better informed, software is affordable, and the results are much, much better. There has never been a better time to get into color management and, as a result, today we see a steady growth in the adoption of color-managed solutions by advertising agencies, prepress houses, photographers, editors, print shops, and printers.

Complicated systems, variable results and over-inflated expectations severely hampered the early adoption of color management, however, the technology is now ready, are you?

Challenges for Color Management

Despite the progress made in color management technology, there remain some challenges facing today's user.

A reason that we have to work harder at color management than at other modern technologies stems from the fact that color management is not the primary business of many supplier companies and is, therefore, not high on their priority list. Different companies are involved in digital cameras, printers and proofers, there are major management information systems and workflow systems, and there are large printing press installations. Often these vendors do not allocate resources to color management design and implementation as this area is often seen as an incidental, ancillary part of the operation. Likewise, on the customer-side, even after making a large equipment purchase, customers will not invest a little more for color management. So, despite the obvious return on investment, both vendors and customers tend to ignore color management.

There has been a shakeout in the industry, some companies have folded, others have been acquired by larger organizations, and some have diversified into other areas. This means that many of the current color management solutions contain mixed, legacy code. An infamous American thanksgiving favorite is called "tur-duck-en", a dish consisting of a deboned chicken stuffed into a deboned duck, further stuffed into a turkey. All of the major color management solutions on the market today are "tur-duck-en" solutions, which sometimes creates a poor user experience.

Due to amalgamation in the industry, it is very common for a vendor to offer color management as a suite of different products. Instead of offering a single color management product, companies offer a number of separate products under a single umbrella. Typically, the output of one system forms the input to the next. This lack of a coherent, purpose-built solution leads to confusion for the end user and is even confusing to company representatives who advise and sell these bundled product offerings.

Poor software design and a non-intuitive user interface continues to plague color management. The ICC specification, for example, describes a color conversion process known as a rendering intent. The official name for one of the rendering intents is "relative colorimetric", but a major vendor offers a drop-down menu for this rendering intent called – “Full (Output GCR)”. How is the user supposed to guess relative colorimetric from “Full (Output GCR)”? In another example, a leading color imaging company has a dialog labelled “CIE Illuminant D50K”. An important distinction, explained in this text, is that Illuminant D50 and 5000K are two separate specifications, there is no such thing as an “Illuminant D50K”!

These examples demonstrate that color management software is usually very confusing to work with. Good software design and an elegant user interface are not part of today’s color management solutions and applications. Today it is incumbent on the user to know what it is they are trying to achieve and how they want to achieve it, the user must seek to achieve their goals despite color management software interfaces.

A perennial challenge for color management is that it is a solution trying to satisfy two very different audiences – the consumer who wants automatic color control and the commercial user who wants to tweak and adjust and control every aspect of the imaging process. Using an automobile analogy, the general user would like a car with automatic transmission with just two pedals, for accelerator and brake. Commercial/professional users prefer a car with manual transmission, with the ability to accelerate through the lower gears, monitor the rev counter, and use the engine for braking.

At the car dealership, you can choose between cars with automatic or manual transmission, in color management there is only one solution – one size fits all. This means that color management is often too complicated for the general user, yet too “dumbed down” for the commercial user. A continuous challenge in color management has been in keeping both camps happy, while sometimes it seems that solutions fall between two stools and both parties are dissatisfied.

A fundamental challenge in color management is that the underlying color science of the process is imperfect. Color is perceived by the eye-brain visual system, and our response to color is based on a number of factors, including such diverse things as the room lighting, what is in the scene, and the mood or age of the observer. Color is thus a very complex phenomenon and there are many nuances in the way that humans see color.

To manage color, we use a number of color measurement systems, but none of these are able to create an exact correlation with human vision. As color management systems are built upon these inexact foundations, sometimes things don’t work out and we don’t get the colors we expect. Color science is not static, there are ongoing improvements, and a number of new approaches to color measurement are described in the text. In general, however, most of the problems with color management are caused by user error and the wrong settings or processes, and the ramifications of the imperfect, underlying color science will only be noticeable in very extreme cases.

How I Came to Write This Book

I worked for a number of years as a Senior Engineer in the Colour & Imaging Technology research group at FujiFilm Electronic Imaging, United Kingdom (which used to be Crosfield Electronics). There I was involved in the development of ICC color management algorithms and software. The seed for this book was sown during those days at FujiFilm, not only in the form of the work I was asked to do, but by the fact that I was often dragged from the research laboratories to the training department to make presentations to our field engineers, distributors, and customers, about the philosophy and benefits of color management. Many ideas and analogies developed in those early training sessions have evolved and found their way into this text.

I have spoken on aspects of color management around the world at numerous trade shows, conferences, symposia, and short courses. During these presentations I have been repeatedly asked for a good book on the topic. I could never give a satisfactory answer because there was only the choice between very technical tomes or vendor literature.

I have taught courses in color management at Western Michigan University, including IMAG 157 Imaging Systems and IMAG 357 Digital Color Imaging. I now teach a course, GCM 360 Colour Management for Graphic Communications at Ryerson University. There is no text that covered in one place all the necessary images and information to explain color management. I was continuously referring to pages in one book for one concept, directing students to a website for another image, and using vendors booklets for other data. There is a lot of information out there, but it is spread over the Internet, in white papers, and in specific book chapters. There was no single text that met my needs and had material that was accessible to the general user.

I realized that I had a unique combination of skills; I have industrial experience from my years at FujiFilm and I am a trained educator with the ability to explain complicated concepts using simple analogies. I realized that I was in a unique position to understand and explain color management. It seemed that the only solution was to write a book myself. Thomson Delmar published the first version of this book in 2004 and John Wiley & Sons, in conjunction with IS&T, has published this updated and totally re-written second edition in 2018.

Intended Audience

Because color management is a new technology, we do not have a workforce that went to school to learn color management. Until we have the next generation of color-savvy graduates, we have a large workforce for whom color management is something new, something that has come about during their working life. Thus, we have a huge demand for job-based retraining.

The book will be useful for professionals such as digital photographers, production managers, print buyers, designers, prepress operators, printers, R&D personnel, color management consultants, trainers, and many others whose jobs involve working with digital color. This book is also of interest to individuals working in ink and paper companies.

It is important that colleges and universities introduce courses in color management so that the next generation of graduates are comfortable with the new workflows. This book is intended for use in undergraduate, graduate, and research programs in digital color imaging, photography, color science, computer graphics, graphic design, communications, multimedia, prepress, and printing.

It is necessary to invest some time in establishing a color management system. How you choose to introduce a color-managed workflow is up to you. You may decide to do this in stages, replacing one part of an existing system at a time, or you may decide to establish a color-managed system in parallel with existing practices. You may be able to designate a single person in your company to take charge of the process, and that person can establish operational procedures for other employees. Whatever method you choose, you will find that the initial investment in this technology is repaid many times over by the advantages and benefits the system has to offer. Whatever route you choose, education and knowledge are key components of any successful color management implementation.

Textbook Organization

In this book there is less emphasis on step-by-step instruction, in using menus and commands from specific applications. This is not an omission but a deliberate strategy for a number of reasons. It is more important to convey the general principles of color management than specific device/software instructions. Suppose you were teaching somebody to drive. You could say, on a Ford Explorer, "move the lever near the left-hand side of the steering wheel to move your side mirror outwards". This is very specific to a particular make and model and is only relevant to owners of Ford Explorers. It would be more useful if we said, "adjust your side mirror to give a clear view of the side and rear of your vehicle". It is more important to understand the outcome of the procedure than how it is achieved in a particular instance.

Other reasons that this text steers clear of specific software/device-based workflows is that software is continually updated, and examples from specific versions will quickly date the material. Finally, with so many possible software-device combinations, it would be impossible to satisfy every user, so the text uses real-world examples where appropriate but concentrates more on explanations and procedures.

The chapters are arranged in such a manner that early chapters develop fundamental concepts and introduce the reader to color science basics. Later chapters concentrate on applications and practical color management with different, real device types. If you are an experienced user, then you can dip in and out of the text as required, while a new user will find it useful to deal with the material in a sequential manner.

This text assumes very little prior knowledge. However, a familiarity with rudimentary computer operations (like opening, saving, and printing) will be helpful. Very little technical experience is required, but the ability to work with digital images, such as TIFF and JPEG file types, and PDF files, will be useful.

Chapter 1, Introduction, provides an introduction to color management. This chapter explains why color management is needed and provides a simple explanation of how color management works. This chapter provides a complete overview of the subject and introduces topics such as L*a*b*, IT8 test charts, profiling software, the International Color Consortium (ICC), and RGB versus CMYK workflows. Chapter 1 is necessary reading because many subsequent chapters are put into context here. Throughout Chapter 1 we flag topics that appear later in the book.

Chapter 2, Principles of Light and Color, deals with the fundamentals of light, color, and human vision. This chapter explains how we see color and shows how the color of an object can change with the color of the light source. This chapter defines CIE illuminants such as D50 and D65 and also explains effects such as chromatic adaptation and metamerism.

Chapter 3, Color by Numbers, introduces CIE-based specification of color. The focus of this chapter is to describe the main color specification systems used in color management, namely XYZ, Yxy, and L*a*b*. The chapter shows how to measure the difference between colors using ΔE.

Chapter 4, Measuring Instruments, provides an overview of the range of different devices on the market today. There are a wide range of colorimeters and spectrophotometers, and there are many new, iPhone-based entrants into the market. This chapter describes the different categories of instruments and briefly describes how they work and how to choose a device appropriate to your needs, including the all important M1 measurement mode.

Chapter 5, Inside Profiles, examines the contents of a profile. This chapter reviews profile inspector programs that can be used to examine the profile header and tags. A concept fundamental to much of color management is the lookup table. Lookup tables are explained using an example from a real device. Some aspects of Chapter 5 are intended for the advanced user, or the user interested in "under-the-hood" color management.

Chapters 6, 7, and 8 look at digital camera, monitor, and printer profiles, respectively. Each chapter describes the process of making and using these device profiles. Chapter 6, Managing Color in Digital Cameras, also includes a section on scanner profiling. Chapter 7, Monitor Profiles, covers desktops, laptops and flat-panel displays, and also web browsers and tablet devices. Chapter 8, Press and Printer Profiling, is an extensive chapter that considers device calibration, reference printing conditions, and issues relating to profiling desktop printers and commercial printing presses.

Chapter 9, Spot Colors & Expanded Gamut Printing, is a chapter, new in this Second Edition, that introduces spot color and expanded gamut workflows.

Chapter 10, XML and Color Management, considers the use of XML in color management applications.

Chapter 11, Color Management in Photoshop, provides a guide to the settings and use of the color management aspects of this popular program. This chapter explains some basic principles for working with color in Photoshop and other Adobe programs and provides a very useful road map to color management operations. This chapter provides an example of a full color management workflow from digital capture, to viewing, to print. Adobe Photoshop represents an excellent color management implementation and correct use of ICC terminology, and is used to demonstrate a complete color management process.

Nomenclature and Abbreviations

L*a*b* is a color metric, written as three numbers, e.g. 52, 45, 67. The L*a*b* system was approved by the Commission Internationale de l'Eclairage (CIE) in 1976 and is officially known as CIE 1976 L*, a*, b* with official abbreviation of CIELAB (pronounced "see-lab"). Historically, different versions of Lab exist, such as Hunter Lab and Adams-Nickerson Lab. In order to distinguish from these other versions of Lab, the official CIE version uses an asterisk – L,*a*,b* – which is pronounced "l-star, a-star, b-star". For clarity and brevity, we use this unofficial syntax throughout this text – L*a*b*.

ΔE comes from the Greek symbol Δ, which stands for "delta" and is used in scientific literature to represent a difference. The "E" comes from the German word "empfindung", meaning a difference in sensation. Thus, the notation ΔE is pronounced "delta E" and signifies a metric for the color difference between two samples. There are different versions of ΔE such as: ΔE^*_{ab}, ΔE_{CMC}, ΔE^*_{94}, and CIEDE2000. Throughout this text, we use the abbreviated – but unofficial symbol – ΔE and, by default, if no particular method is specified, CIEDE2000 is assumed.

Occasionally in the text, the price of a product or service is quoted, the currency used is indicated by the $ symbol and refers to the US$.

Throughout this text, the American spelling of color is used, we use "color" not "colour", except for company names or document titles, for example, *ISO 12646 – Graphic technology – Displays for colour proofing.*

Color management is more or less platform independent. However, I am a Mac user, and when I wrote this book I was running macOS X. Most of the examples and screen captures are therefore based on macOS X. However, the concepts developed throughout the text are applicable to both Windows and Mac users. In the main, readers of all persuasions will be able to read, follow, and implement the ideas developed in this text.

Acknowledgments

It is important to recognize and acknowledge the contributions of many colleagues for their valuable suggestions and technical expertise. Some colleagues have directly commented on the text, others have indirectly contributed to my understanding of color management through many enlightening conversations over the years. The phrase used in colleges and universities is “life-long learning”, and I humbly admit to learning so much from the following experts over the course of preparing this text.

I take full responsibility for any errors and omissions in this text, however, if you find the work informative, it is probably due to the input of the one of the following esteemed colleagues. It gives me the greatest pleasure to acknowledge the contributions of the following individuals (in alphabetical order by last name):

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Typesetting was conducted in LaTeX at Aptara Inc. in India. PDF proofs and print-ready files were created using internal LaTeX software. Adobe Photoshop and Adobe Illustrator were used to process the color images. Images were saved in RGB JPEG/PNG format optimized for screen resolution in production of the digital versions of the book. This book was printed at Markono in Singapore using offset lithographic printing with CMYK process inks on a Heidelberg Speedmaster SX 102 press. Paper used for the text is 90gsm UPM Classic and cover is 130gsm Art. Printing targeted the FOGRA39 reference printing condition. CGS ORIS Press Matcher software was used to control color accuracy and consistency.

1

Introduction

Objectives

- Explain and define color management.
- Describe the older, closed-loop method of color control.
- List the activities of the International Color Consortium (ICC).
- Describe the three Cs of color management – calibration, characterization and conversion.
- Introduce RGB/CMYK colorspaces and Yxy/L*a*b*.
- Introduce typical color management workflows.
- Describe the benefits of a color management system.

1.1 Why Do We Need Color Management?

What is color management and why do we need it? Why can't we just use a digital camera to take a picture, view the image on a display, print it out, and have the color match throughout? The answer is that every imaging device is different and every device has its own particular characteristics.

To understand device characteristics, consider an analogy of making microwave popcorn, Figure 1.1. Through trial and error, it is possible to determine that a home microwave needs, for example, exactly two minutes to pop all the kernels without burning any. For a higher wattage, office microwave however, two minutes is too long, and it is determined that the cook time must be adjusted and reduced to one-and-a-half minutes. In a student apartment, using a weak mini-microwave, it is determined that three minutes is needed to create the perfect snack. In all instances we can achieve the same result – a perfectly popped bag of popcorn – but we must adjust the cooking time to take into account the wattage and settings of each microwave, in other words, the characteristics of each device.

In digital imaging, we may have an image with a yellow lemon, Figure 1.1. We seek to create this yellow color on different devices. Each printer prints in a different way, with different ink or toner and each device may use different media. To create this yellow color on different devices we must take into account the characteristics of each device.

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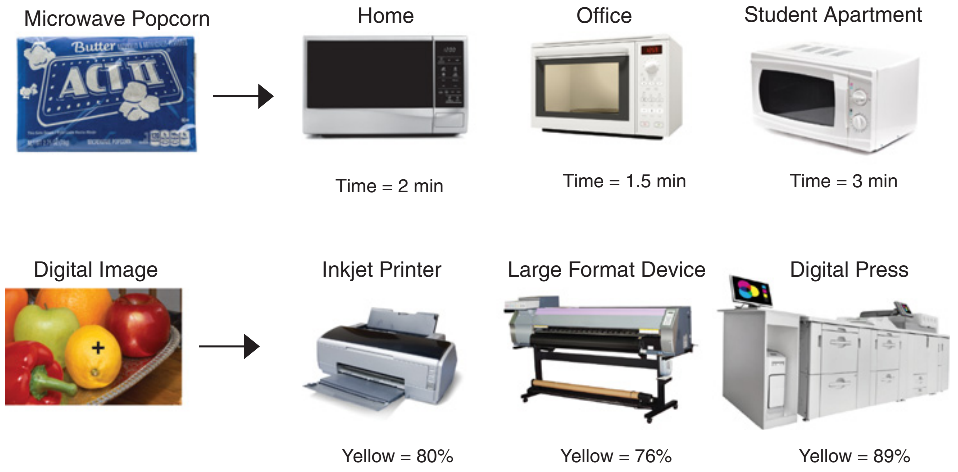


Figure 1.1 Microwave popcorn needs different cook times on different appliances. Similarly different printing systems require different pixel instructions – color management is all about creating different instructions to get the same color on different devices.

In the same way that we adjust the cooking time of popcorn to accommodate the characteristics of each microwave oven, similarly we must adjust the printing instructions to take into account the characteristics of each printing system.

The amount of ink is expressed in units of percent, such as 40%, 50%, 60%, etc. (In this context % is simply an amount and not a percentage.) In Figure 1.1, an inkjet proofer may need 80% of yellow ink, while a large format device may have a very strong yellow ink set, so it may need only 76% of yellow ink to create the same color. A digital press may require 89% of yellow toner to create the same "lemon yellow".

So we see that in order to achieve the same color on different devices it is necessary to send different instructions to each device. In the case of popcorn it may be easiest to determine the required cooking time simply via trial and error, but for an image we need a more sophisticated approach as we must consider not just yellow, but green and blue and orange and all the other colors that can be present in an image. And of course we must extend the process beyond printers to include any device in a color imaging system, including images viewed in a web browser, or a tablet device, or printed using an offset printing press, etc. *Color management is a technology that enables the computation of appropriate pixel instructions on a device by device basis.*

Color management is a digital technology framework that can be used to compute device-specific instructions and thereby control color among different devices in an imaging system. *Color management is defined as the use of hardware, software, and processes to control and adjust color among different devices in an imaging system.*

Color management is not just the technology, it is not a physical item on a store shelf that you can go and buy, color management is all about systems, processes, software, measuring instruments – a whole philosophy – a systematic framework for color control – a way of life!

This chapter provides an introduction to color management, what it is, and how it works.

1.2 Closed-loop Color Control

A fundamental issue with color imaging is that each device behaves differently, which means that we cannot send the same pixel values to different devices; we must adjust the pixel values in order that they are appropriate for each device. There are two ways of making these adjustments, the traditional way is called *closed-loop color*, and the new way is *open-loop color*, more commonly referred to as color management.

Affordable devices for color imaging are a relatively recent development that have come about because cheaper digital systems have brought the technology within the reach of the mass market. During the 1970s and 1980s, digital color was the preserve of high-end systems such as those sold by Crosfield Electronics, Hell, and Dainippon Screen. The same manufacturer would provide a color imaging suite that included the monitor, software, scanner, proofer, and so on. These were closed-loop systems in which all devices were designed and installed by one vendor.

An example of a closed-loop system is shown in Figure 1.2. The image was always acquired from a photographic scanner (perhaps a drum scanner), it was always displayed on the same monitor, and the images were destined for one type of print process, e.g. an offset print condition, that was emulated by a proprietary proofing system such as ColorArt or Chromalin. In this closely controlled situation it was relatively easy to obtain the color we wanted. However, two important conditions had to be met: a fixed workflow and skilled personnel.

In closed-loop systems it was necessary to have a trained scanner operator. Through many hours of use, the operator would gain knowledge about the characteristics of a particular scanner and the required tone curve corrections needed. Images were acquired directly into cyan, magenta, yellow, and black (CMYK), as appropriate for a known print condition.

To obtain optimum results, the operator generated a set of actions that were necessary to apply to scanned images. Typically, this set of corrections would vary depending on such things as whether the image was low key or high key, whether it had dominant skin tones, which customer the job was for (and their color preferences), and how the job was to be printed. Color corrections were based on the operator's experience, and the operator would use CMYK values shown by a dropper tool to make adjustments, Figure 1.3.

Along with a skilled operator, the other requirement of a closed-loop system was a fixed workflow. That is, it was necessary to know where the image came from, how

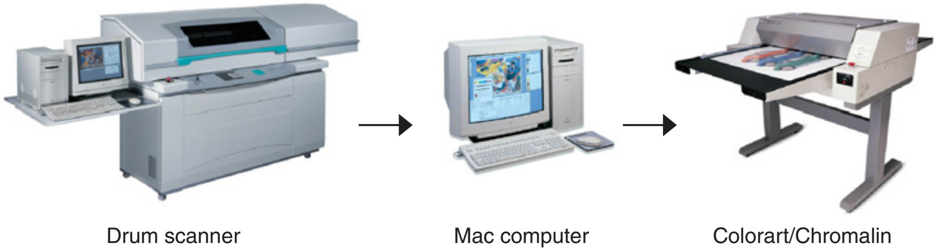
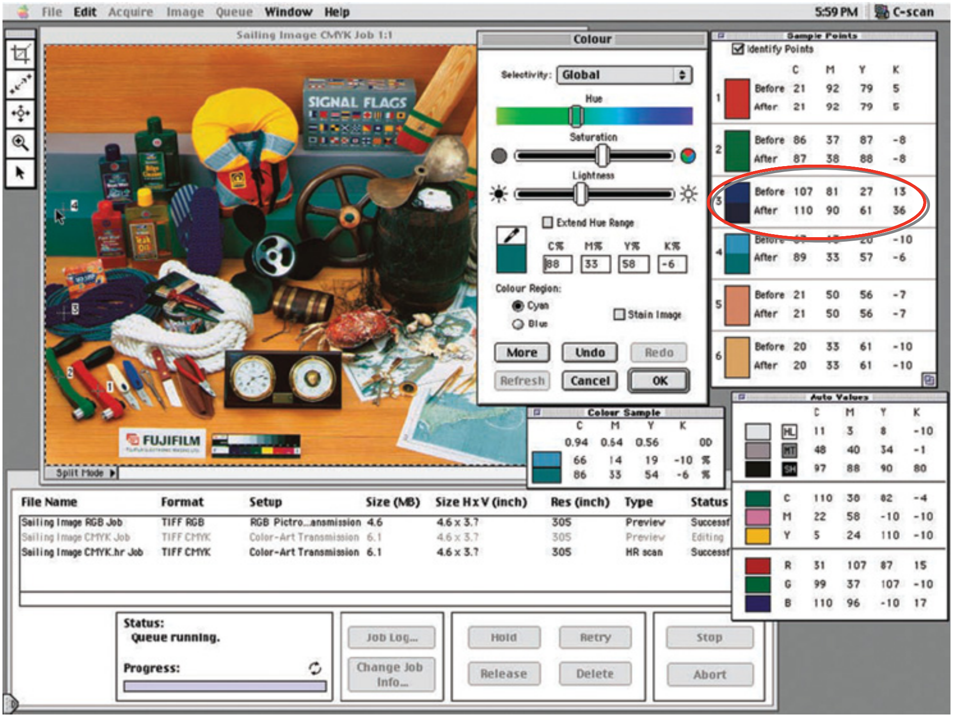


Figure 1.2 In the old days, digital color was the preserve of high-end systems, where the same company, such as Crosfield Electronics, would provide a color imaging suite that included a drum scanner, monitor, software, and proofing system.



Selectivity: Global

☐ Extend Hue Range

C%	M%	Y%	K%
88	33	58	-6

Colour Region:
● Cyan
○ Blue

☐ Stain Image

Sample Points

☑ Identify Points

		C	M	Y	K
1	Before	21	92	79	5
	After	21	92	79	5
2	Before	86	37	87	-8
	After	87	38	88	-8
3	Before	107	81	27	13
	After	110	90	61	36
4	Before	[illegible]	[illegible]	20	-10
	After	89	33	57	-6
5	Before	21	50	56	-7
	After	21	50	56	-7
6	Before	20	33	61	-10
	After	20	33	61	-10

Colour Sample

C	M	Y	K	
0.94	0.64	0.56		0D
66	14	19	-10	%
86	33	54	-6	%

Auto Values

	C	M	Y	K
HL	11	3	8	-10
MT	48	40	34	-1
SH	97	88	90	80
C	110	30	82	-4
M	22	58	-10	-10
Y	5	24	110	-10
R	31	107	87	15
G	99	37	107	-10
B	110	96	-10	17

File Name	Format	Setup	Size (MB)	Size H x V (inch)	Res (inch)	Type	Status
Sailing Image RGB Job	TIFF RGB	RGB Pictro...ansmission	4.6	4.6 x 3.7	305	Preview	Successf
Sailing Image CMYK Job	TIFF CMYK	Color-Art Transmission	6.1	4.6 x 3.7	305	Preview	Editing
Sailing Image CMYK.hr Job	TIFF CMYK	Color-Art Transmission	6.1	4.6 x 3.7	305	HR scan	Successf

Status:
Queue running.

Progress:

Figure 1.3 In closed-loop systems experienced operators edited images not on visual appearance, but using CMYK pixel values – this required considerable experience. Image shows C-scan software from FFEI.

it would be viewed, and how it would be printed. The relationship between devices was learned through a lengthy, iterative process, and it was not easy to swap devices. If images arrived from a different scanner system, or were to be sent to a different printing configuration, a job would have to be reworked.

There were other issues with this way of working. The image edits were stored in proprietary file formats and were not portable among different software systems. It was difficult to upgrade or change products without losing many man hours of customized style files.

In summary, we see that imaging devices have always exhibited some variability and specific color characteristics. The way of dealing with these characteristics in the older, closed-loop way of working was to "learn" the characteristics of each device through trial and error. Today's requirements make closed-loop color appear very expensive, inflexible, proprietary, and personnel dependent.

1.3 Need for an Open System

For many years, closed-loop color worked very well and was able to achieve high-quality results. The operator learned the device characteristics and then compensated for the devices' behavior. Why is it not possible to simply extend that way of working to today's environment?

In modern workflows, images come from a number of places, are viewed on different displays, and are sent to different printer and other output systems. Consider a scenario in a modern prepress facility that uses closed-loop color. Suppose we have an in-house photo studio and an operator who is experienced with editing product shots from a particular digital camera. The company has an inkjet printer, and all images are printed on this device. When images are captured, the operator adjusts them so that they print correctly on this printer.

Now suppose the company's business grows and it creates a second studio bay and acquires a different camera make and model. Initially the color of the new camera's images may not be perfect. However, over time the operator will learn the "characteristics" of the new camera system and will know how to adjust images that originate from that source. Next, suppose the company starts to use an external freelance source. Again, the operator will need to learn the unique characteristics of this external source and eventually will be able to appropriately adjust images that originate from the freelance photographer. The company does well and the volume of business means that the company has to install another printer. It chooses a laser toner device.

Now the (slightly frustrated) employee has to make different changes to the image, depending on whether the image is going to be printed on the inkjet printer or the new color laser device. The operator tries to keep track of all of these device-specific conversions. Then the boss comes in and asks for an image to be created that is to be sent to a client's location for the client to view on their monitor and print on their printer. At this point the operator gives up and starts muttering things about using color management!

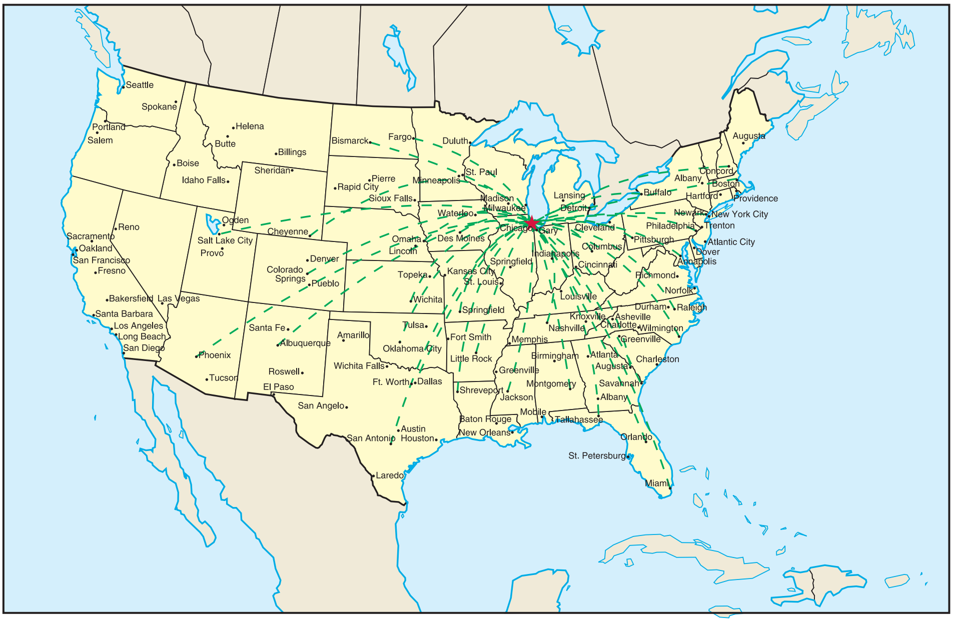
A closed-loop system does a compensation for each device-to-device translation, and therefore the closed-loop color system works best only for a small number of devices. Today, with many different input and output devices, the closed-loop system of trying to compensate for the behavior of each device on a device-by-device basis is impractical as it leads to a multitude of "connections". The other prerequisite of closed-loop color is a skilled operator.

As the conditions for a closed-loop system (a fixed, small number of devices and skilled personnel) disintegrated something had to be done to get consistent, accurate color. The answer is an open-loop system, also known as a color management system. A color management system changes the pixel values in an image – behind the scenes, and without direct user input.

1.4 A Color Management System

Today, color is managed in an open-loop system, that we refer to as a *color management system*. Today images are captured with digital cameras and smartphones, are viewed on tablets, laptops and monitors, and sent to online portals and publications. Images destined for print have a wide range of printing technologies to choose from, spanning offset publication printing to packaging and large format systems for signage applications. Given this scenario of images coming from many different devices and going to many different forms of output, a closed-loop solution is largely impractical.

A color management system provides an elegant solution to the issue of color control. Instead of trying to understand the relationship between every device and every other


Seattle
Spokane
Portland
Salem
Helena
Butte
Billings
Bismarck
Fargo
Duluth
Augusta
Boise
Idaho Falls
Sheridan
Pierre
Rapid City
Minneapolis
St. Paul
Sioux Falls
Concord
Albany
Boston
Lansing
Buffalo
Hartford
Providence
Madison
Milwaukee
Detroit
Waterloo
Newark
New York City
Reno
Ogden
Cheyenne
Chicago
Gary
Cleveland
Philadelphia
Trenton
Sacramento
Oakland
Salt Lake City
Provo
Omaha
Lincoln
Des Moines
Pittsburgh
Atlantic City
San Francisco
Fresno
Denver
Indianapolis
Columbus
Dover
Annapolis
Colorado Springs
Pueblo
Topeka
Kansas City
Springfield
Cincinnati
St. Louis
Richmond
Bakersfield
Las Vegas
Wichita
Louisville
Norfolk
Santa Barbara
Durham
Raleigh
Springfield
Los Angeles
Long Beach
Santa Fe
Tulsa
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Asheville
Charlotte
Wilmington
San Diego
Amarillo
Albuquerque
Fort Smith
Nashville
Memphis
Greenville
Oklahoma City
Phoenix
Birmingham
Atlanta
Charleston
Little Rock
Augusta
Wichita Falls
Roswell
Greenville
Tucson
Ft. Worth
Dallas
Montgomery
Savannah
El Paso
Shreveport
Jackson
Albany
San Angelo
Mobile
Baton Rouge
Tallahassee
New Orleans
Austin
San Antonio
Houston
Orlando
St. Petersburg
Laredo
Miami

Figure 1.4 Airlines use a hub system to connect passengers between different cities. This is efficient as it reduces the number of flights needed to cover many destinations.

device, a color management system employs a central connecting space. Consider an airline analogy to understand how modern-day color management works.

Airlines have developed the concept of a "hub and spoke" system, depicted in Figure 1.4. Flights from cities served by an airline fly into and out of a central hub (e.g. Chicago O'Hare). Suppose a passenger wants to fly from City A to City B. The passenger catches a flight from City A into the central hub and then catches a connecting flight from the hub to City B. It is thus possible to get from City A to City B even if there is no direct flight between A and B.

If every city had to be directly connected to every other city, this would require a huge number of flights. A big advantage of the hub and spoke system is that it dramatically reduces the number of flights needed to cover many destinations. The other advantage of the hub and spoke system is that it is very simple to add a new city to the route. All that is needed is a single flight from City C into the central hub and instantly City C is connected to Cities A and B and the rest of the airline's network.

How does this analogy relate to color management? Modern-day color management uses a central hub system to communicate color between devices, as shown in Figure 1.5. The official name for the central hub is the Profile Connection Space. A file, called a color profile forms the "spokes" of the system. A color management system uses color profiles to connect devices into and out of, the central connection space.

If you are a traveling passenger, and seek to enter the airport terminal, you must have a boarding pass, similarly for an image to be part of a color managed system it must have a color profile. Thus, we need a scanner profile for a scanned image, a digital camera profile for a camera image, a monitor profile for an image to be displayed on a monitor,

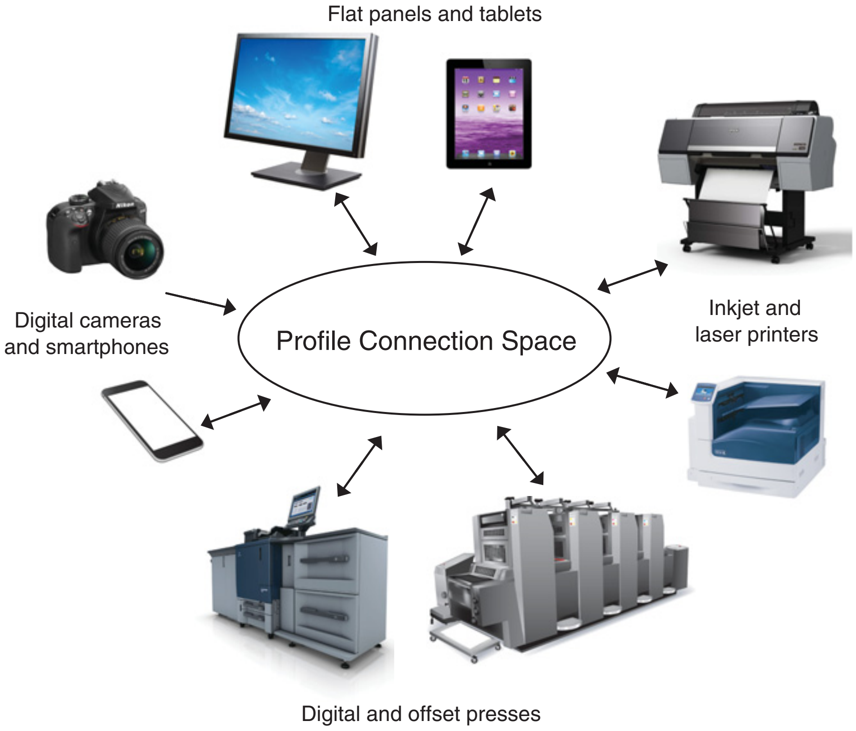

Flat panels and tablets
Digital cameras and smartphones
Profile Connection Space
Inkjet and laser printers
Digital and offset presses

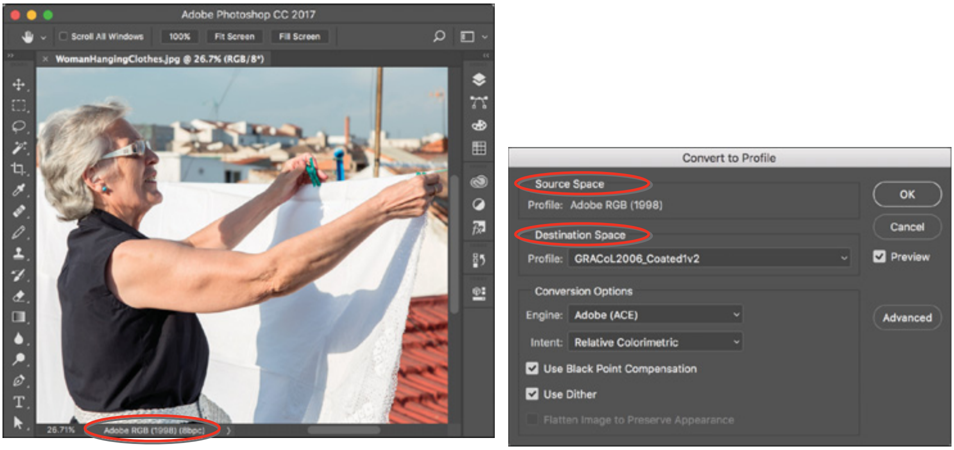
Figure 1.5 A color-managed system uses the Profile Connection Space to connect many devices via device profiles. This figure is the single most important schematic to understand in color management. *Source:* Konica Minolta Business Solutions, Ingram Image, Epson®, Xerox® and Nikon Corporation. Image from Konica Minolta Business Solutions, reproduced with permission. Images of iPad and LCD panel licensed by Ingram Image.

and a printer profile for a printed image. *The device color behavior is encapsulated by a profile, so as an image completes its journey, into and out of the central hub, the pixel data in the image is automatically adjusted by the profile to take into account the characteristic behavior of each device.*

In Figure 1.5, note the arrows, leaving the Connection Space going to an inkjet proofer and laser printer; the action of the profiles is to adjust and alter the pixel values for each device, exactly what we need to happen from the earlier popcorn analogy.

Color management can only work if every image has a profile. By simply opening an image in Adobe Photoshop, it is possible to see that an image has an associated profile, in this example the name of the profile is "Adobe RGB (1998)", Figure 1.6a.

Another feature of a color-managed process is the source and destination profile. In the airline analogy, passengers fly into and out of a central hub, similarly in color management we need to know where the image is coming from and where it is going to. Color management operations require the user to specify a source and a destination profile. The source and destination profiles are clearly illustrated in a Photoshop dialog, Figure 1.6b. This figure shows a commonly used RGB to CMYK "travel plan", where an image is starting from a source space with a profile called "Adobe RGB (1998)" and



WomanHangingClothes.jpg @ 26.7% (RGB/8*)

26.71% Adobe RGB (1998) (8bpc)

Source Space

Profile: Adobe RGB (1998)

Destination Space

Profile: GRACoL2006_Coated1v2

☑ Preview

Conversion Options

Engine: Adobe (ACE)

Intent: Relative Colorimetric

☑ Use Black Point Compensation

☑ Use Dither

☐ Flatten Image to Preserve Appearance

(a) (b)

Figure 1.6 (a) Adobe Photoshop clearly indicates the image's profile at all times. © Eduardo López/ Adobe Stock. (b) Every color management operation requires the user to specify a source and destination profile.

is traveling to its destination indicated by a profile called "GRACoL_2006_Coated1v2". (RGB and CMYK are abbreviations for red, green, blue, and cyan, magenta, yellow and black, respectively.)

Color has become "plug and play" – just as it is easy for an airline to add a new city to its route map, in color management it is easy to add a new device to a workflow. All that is needed is a single profile. The profile connects the device to the central connection space which immediately makes the characteristics of the device known to all other devices in the system, making it is easy to add, delete or change devices.

A city can sometimes be one person's starting point, but it could be another passenger's final destination. In Figure 1.5 we see that most processes are connected by a double-ended arrow. A smartphone could be used to capture images for input to a color managed workflow, but it is also often used to view content from a color managed process.

In summary we can say that device variability has not been eliminated, but in an open-loop color management system, profiles and the Profile Connection Space are used to deal with device variability. A color management system connects different types of color imaging devices and provides a way to alter the underlying pixel values in an image as images flow seamlessly between different color imaging devices.

Figure 1.5 is the single most important diagram to understand in color management. This figure provides the conceptual basis for all color management operations as discussed throughout this text.

1.5 Color Management Workflows

A *workflow* describes a path involving different devices and operations. A color management workflow can consist of input, output, and display devices connected to a central connection space via profiles, Figure 1.5. There are a number of ways of processing images through such a system.

A fundamental function in color management is *accurate viewing* of an image. In this scenario, the image from a digital camera or smartphone is brought into the central space and then sent to a monitor. This process is accomplished using software that applies a source profile (the camera profile) and a destination profile (the monitor profile) to the data in the image.

On the way in, the camera profile provides information relating to the capture device's color characteristics and on the way out the image is adjusted to take into account the particular monitor being used to view the image. The end result is a color-correct rendition of the starting image. If the image is sent by e-mail to a customer, the customer can also accurately view the image. In this scenario, the same camera profile is associated with the image, but on the way out the customer is using their own monitor and so must have their own monitor profile. In this instance, the image pixel data is adjusted to take into account the customer's monitor being used to view the image.

The real power of color management is evident in printer-based workflows. Color management facilitates *accurate printing*. This is where the image from a digital camera is brought into the central space and then sent to the printer. In this case the software applies the input profile (as before), but instead of a monitor profile the system uses an output profile. The printed result is thus color managed and may be similar to the original, given limitations of the destination printing system.

Next, consider the common situation in which you are looking at your image on your screen and are ready to print it. Using profiles, you can determine whether or not your image colors are going to be changed by the printer.

Soft proofing involves previewing the printed image on a monitor so that we can get a color-accurate preview of what the printed result will look like, Figure 1.7. In this scenario, the image is brought into the central connection space using the input profile. The image is then processed through the output profile, which imbues the image with the look and feel of the printer. From the printer space, the image is brought back into the central space and finally sent to the monitor. A soft proof is very useful in that simply by choosing a printer profile, you can immediately see on the screen what your print is expected to look like.

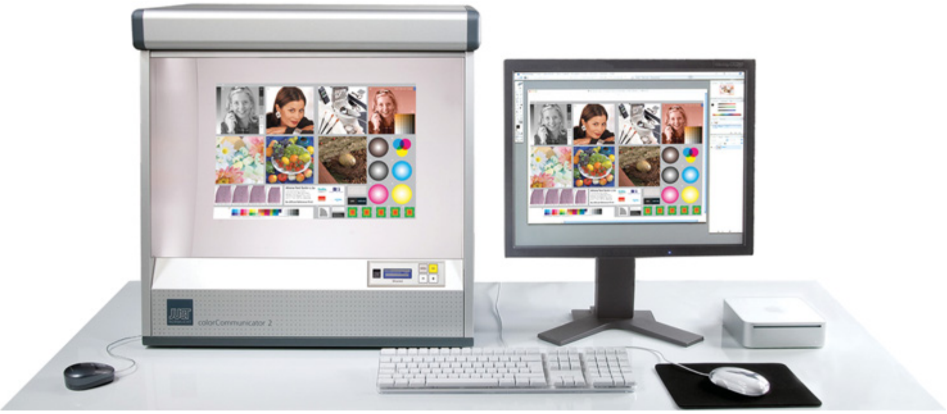


Figure 1.7 In a process known as soft proofing, the image on your screen matches the printed output displayed in a desktop viewing booth. Reproduced with permission of JUST Normlicht®.

A very big time (and money) saver is *press proof*. This process simulates a printing press result on a local desktop proofer, so that you can see what an image will look like before thousands of copies are printed. In the press proof scenario, the image is brought into the central space via the input profile. The image is then processed to the press profile, brought back in from the press, and finally sent out to a local inkjet proofer. The inkjet device provides a rendition of the printed product and therefore provides a preview of the printed result that can be used to detect any problems with the print job. As the inkjet proof is produced in conjunction with the characteristics of the printing press it accurately represents the capability of the printing press and can be used as a hard-copy proof for customer sign off, safe in the knowledge that the press can achieve the colors shown.

Any device used to simulate the results of another printer is called a *proofer*. In color management, any output device can be used as a printer or proofer. The difference between a printer and a proofer is the sequence in which the profiles are used. The first device in the process is the printer, and the second device becomes the proofer. Care should be taken in choosing a suitable proofer. The proofer should be able to reproduce all colors received from the printer device. Thus, not all printers are suitable proofers.

Printer profiles can be used for *print-to-print matching*. Print-to-print matching is often used where a brand product must be reproduced in a magazine advertisement, flyer insert, product label, store display, etc. In print-to-print matching, output profiles are used to create the same “look and feel” on different print processes. The sequence of profiles used in this situation would be, for example, a camera image with a source profile and a digital press and offset press as the destination profiles.

In order to avail of the benefits of a color managed system, all that is needed is a profile for each device and user knowledge about the sequence in which to apply the profiles. With this information any user can exploit the many useful features of a color managed system.

1.6 ICC – International Color Consortium

Today when we refer to color management we actually mean “ICC color management”. The framework for the Profile Connection Space and the format of profiles, is described by the International Color Consortium (ICC). The ICC is a regulatory body that supervises color management protocols between software vendors, equipment manufacturers and users.

In the early 1990s a number of leading color technology companies were developing applications for desktop color publishing. Because there was no common color management framework for systems to use, each application had to align itself with a specific hardware vendor.

New systems were introduced regularly, and there was no compatibility between systems and no consistency among results. When a desired feature was missing from a chosen solution, users wanted to “mix and match”, i.e. purchase parts of the system from different vendors. The technology was evolving, and there was no system to support the new way of working. The entire industry was threatened.

(a) (b)

Figure 1.8 (a) The birth of the ICC is generally accepted to have been at a meeting in Palo Alto, in 1993. (b) Today, representatives from ICC member companies meet twice a year. ICC meeting in progress, Munich, February 2016. Reproduced with permission of ICC.

At this time, Apple Computer had been working on a color management project called ColorSync^{TM}. The ColorSync philosophy was simple. Just as the operating system knows about things such as resolution and bit depth of a monitor, or the mapping of letters on a keyboard, there should be some way to succinctly describe the color capabilities of a device. ColorSync is an OS-level technology that facilitates the communication of color information among multiple hardware and software components. It is an open-platform system that all vendors can link into. Many vendors were interested in adopting or interfacing with this system, but were secretive about their intentions.

The birth of the ICC is generally accepted to have been at a FOGRA (German graphic technology research association) meeting in Munich, in 1992. After the normal program, the FOGRA organizers invited guests to continue discussions in a small meeting room. In this meeting vendors talked openly about ColorSync and their interest in a unified color management system. The shroud of secrecy was lifted, and the Apple ColorSync Consortium was formed with the first official meeting in 1993 at Sun Microsystems in Palo Alto, depicted in Figure 1.8a.

The Apple ColorSync name was soon dropped from the title, as everyone was in agreement that the consortium should be truly platform independent. A totally independent organization emerged called the International Color Consortium (ICC). The industry has greatly benefited from being able to use the ColorSync model as the basis and framework for modern color management systems and is indebted to the farsightedness of Apple Computer for readily offering its technology to the community.

The eight founding members of the ICC were Adobe, Agfa, Apple, Kodak, Taligent, Microsoft, Sun, and Silicon Graphics. Today, the ICC is open to all companies who work in fields related to color management. Members must sign a membership agreement and pay the dues, which are currently $2500 a year. Different membership categories are available to universities with color imaging programs and to individuals.

The ICC has over 70 member companies who elect a roster of officers from within their ranks. The NPES (Association for Suppliers of Printing, Publishing and Converting Technologies) provides administrative support to the ICC in the form of mailing lists, web sites, organization of meetings, and issuance of an annual report. The ICC web site – www.color.org – provides a useful repository of ICC profiles, a number of profiles for testing, and informative White Papers. The site is widely used and receives 14,000 hits per month.

The work of the ICC is conducted via conference calls and the consortium also meets in person, in different worldwide locations, three times a year. The ICC meeting in February, 2016 in Munich, Germany is shown in Figure1.8b. Normally a member company or organization provides local assistance or an ICC meeting may be held in conjunction with a relevant conference such as the IS&T Color Imaging Conference. At any given meeting, only a subset of the membership is in attendance.

The main work of the ICC is done in groups, each dedicated to looking at a specific issue. Currently there are working groups for Architecture, Displays, Graphic Arts, Profile Assessment, Medical Imaging, and Specification Editing. Each group works on ways to solve problems and tackle user issues. Often the groups need to overcome obstacles posed by the proprietary nature of modern digital imaging systems or patent issues.

The outcomes of the ICC deliberations are communicated to users and vendors via the ICC profile specification. The specification is a technical document that describes the structure and format of ICC profiles and is the main "biblical" document for the ICC. The ICC specification continues to change and evolve, the current version of the specification is always available from the ICC web site. At the time of writing there are the following versions of the specification in use.

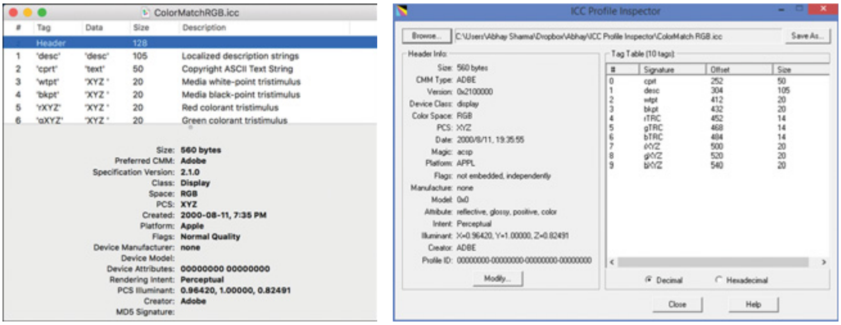
- Specification ICC.1:2001-04 (Version 2), previous major revision, still supported by many vendors.
- Specification ICC.1:2010-12 (Version 4), most widely used version, published in 2010.
- Specification ICC.2:2016-07 (Version 5), released in 2016, not yet in widespread use.

Profiles generated according to each version of the specification are labelled accordingly, thus you may meet a Version 2 (v2) profile, or Version 4 (v4) profile, etc.

The specifications are also submitted via appropriate national and international committees to be published as international standards, ISO 15076 (v2 and v4) and ISO 20677 (v5).

The ICC has created a universal system for color management that has revolutionized and hugely benefited the whole industry. Proprietary systems have been relegated in favor of an open architecture that ensures convenience and seamless interoperability for the end user. One of the reasons that the current system works so well is that the whole community – suppliers, users, operating systems – has come together to agree on the structure, format and contents of an ICC profile. The use of proprietary information in an ICC profile is actively discouraged, so in general there is no, or very little, proprietary information in an ICC profile.

As day-to-day color management involves many different companies and products it is important that profiles made by one company can be used for devices made by another manufacturer and connected by the user in third party application software – all on the Windows or Mac operating systems. As profiles are all made according to the ICC specification, this means that it doesn't matter who made the profile and where we want to use it; profiles work for all devices, on all software, and in all operating systems. The format is so open that if you are a Mac user – double click on any profile and it will open up, Figure 1.9a. On Windows, an ICC profile can be opened and its contents can be viewed with a free utility, Figure 1.9b.



#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'desc'	105	Localized description strings
2	'cprt'	'text'	50	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'rXYZ'	'XYZ '	20	Red colorant tristimulus
6	'gXYZ'	'XYZ '	20	Green colorant tristimulus

Size: 560 bytes
Preferred CMM: Adobe
Specification Version: 2.1.0
Class: Display
Space: RGB
PCS: XYZ
Created: 2000-08-11, 7:35 PM
Platform: Apple
Flags: Normal Quality
Device Manufacturer: none
Device Model:
Device Attributes: 00000000 00000000
Rendering Intent: Perceptual
PCS Illuminant: 0.96420, 1.00000, 0.82491
Creator: Adobe
MD5 Signature:

(a)

C:\Users\Abhay Sharma\Dropbox\Abhay\ICC Profile Inspector\ColorMatch RGB.icc

Header Info:
Size: 560 bytes
CMM Type: ADBE
Version: 0x2100000
Device Class: display
Color Space: RGB
PCS: XYZ
Date: 2000/8/11, 19:35:55
Magic: acsp
Platform: APPL
Flags: not embedded, independently
Manufacture: none
Model: 0x0
Attribute: reflective, glossy, positive, color
Intent: Perceptual
Illuminant: X=0.96420, Y=1.00000, Z=0.82491
Creator: ADBE
Profile ID: 00000000-00000000-00000000-00000000

Tag Table (10 tags):

#	Signature	Offset	Size
0	cprt	252	50
1	desc	304	105
2	wtpt	412	20
3	bkpt	432	20
4	rTRC	452	14
5	gTRC	468	14
6	bTRC	484	14
7	rXYZ	500	20
8	gXYZ	520	20
9	bXYZ	540	20

● Decimal ○ Hexadecimal

(b)

Figure 1.9 ICC profiles are platform independent, so profile contents can be viewed using (a) MacOS system software called *ColorSync Utility* or (b) a Windows utility called *ICC Profile Inspector*.

An ICC profile is a computer file that can vary in size from 4 kB for a simple monitor profile, to an 8 MB printer profile. Profiles can be embedded in an image or be used as standalone files. In terms of the construct of a profile, all devices are considered equal – i.e. the ICC does not distinguish between the profile for a $100 desktop inkjet printer or that for a $1 million offset printing press.

The ICC framework allows companies to develop new products or write new software without the worry of which platform or system to support. ICC color management has enabled quicker time to market and ensured a level playing field. A smaller start-up company has equal access as a behemoth imaging company, encouraging competition and entrepreneurship.

The ICC framework allows for expansion into new technology areas. New devices and systems that were not envisaged at the time of the creation of the ICC nevertheless can be easily accommodated by the ICC's open architecture. Color reproduction on tablets, smartphones and in web browsers; in 3D printing, and in vehicle wraps can all be easily modeled by ICC profiles. New expanded gamut ink sets, using more than CMYK, such as orange, green and violet, do not require any new ICC modules.

Apple's ColorSync technology was the first and best system-wide implementation of a digital color management system and forms the basis for modern-day ICC color management. Because of this historical connection, and because ColorSync continues to be a well-integrated and well-supported part of macOS, this is often the preferred platform for color management.

ICC color management is here today, and is here to stay, it is not going away anytime soon, which is justification for the reader to understand color management and how it works.

1.7 RGB and CMYK Color Specification

In color management we encounter color specification in RGB and CMY (or more commonly CMYK). Devices operate using one or the other of these basic color sets, as shown in Figure 1.10.

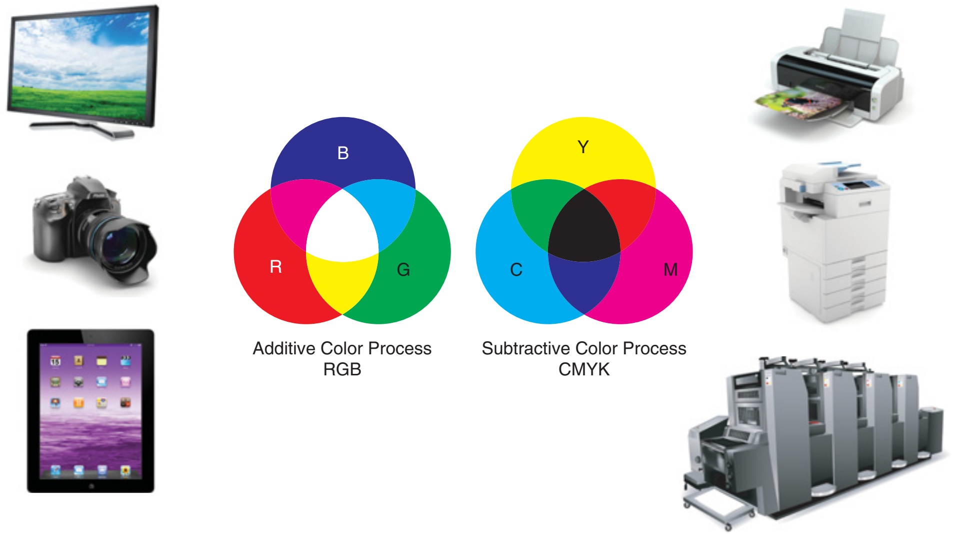


Figure 1.10 Color imaging devices reproduce colors using either the additive RGB color set (red, green, and blue) or the subtractive CMYK color set (cyan, magenta, yellow and black). LCD Panel: © Denis Tabler/Shutterstock.

Some devices create colors using the RGB set (i.e. red, green, and blue). RGB is called the primary (or additive) color set. The technologies that are based on RGB are flat-panel displays, digital cameras, and tablet devices. Cyan, magenta, and yellow (CMY) is the other basic color set. CMY is called the secondary (or subtractive) color set. CMY devices include all printers and presses. In each system the three colorants control a third of the spectrum, thus by the use of varying amounts of RGB or CMY we are able to create a wide range of colors.

In RGB devices, such as a monitor, we can create the primary colors, red, green or blue, using the red, green, or blue elements, respectively. We can also add red, green or blue together to simulate other colors. If we add red and blue this area of the screen will look magenta, if we add blue and green we get cyan and if we add green and red we get yellow. If we add all three colors together the screen will look white, and if we add none of these we get black. Of course we can also add perhaps a bit of red and a bit more of green to make mid-tones and intermediate values. So we see that by controlling the primary R-G-B colorants we can create any color we want.

The other main color model is the CMY model. In the CMY model, for offset printing, for example, we place different amounts of cyan, magenta and yellow ink on the paper to create any of the colors we want. We can add one, two, or three colored inks together and also differing amounts of each ink. If we add yellow and cyan ink we form green, and cyan and magenta ink create the impression of blue, finally magenta and yellow ink makes red. Where we put down all three color inks in one spot this appears as black. If we want to make white, we put down no ink and the paper shows through making white.

In printing, because of the imperfections in inks, pigments, and toners the black formed by the addition of cyan, magenta and yellow is not that deep or vivid, so we artificially introduce a black ink (K), therefore the CMY set is commonly known as

Table 1.1 RGB and CMYK are instructions for a device and therefore only give a general indication of the final color.

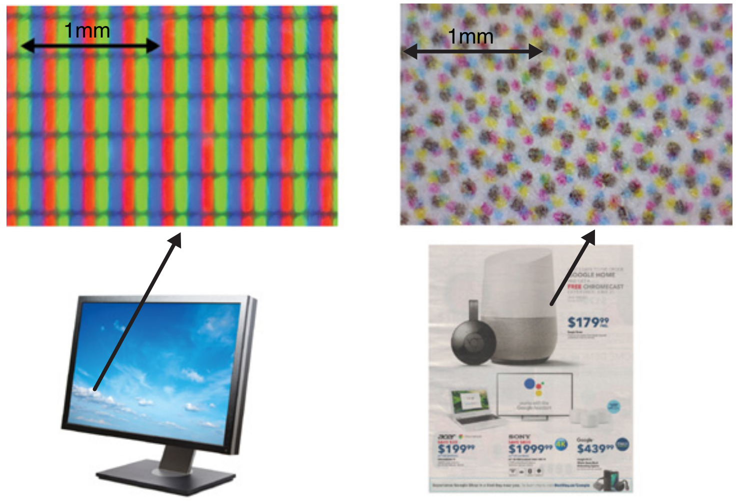
Color Model	Pixel Value	Color
RGB (0–255)	R = 10, G = 200, B = 32	🟩
CMYK (0–100%)	C = 13%, M = 6%, Y = 83%, K = 4%	🟨

CMYK. Black is called "K" due to historical reasons where the black channel was the key or keyline channel and the other physical color separations were aligned to the black channel for registration purposes. (Also if black had been referred to as "B", it could be confused for blue.) In most printing processes therefore, we add black ink or toner to improve the colors in the image. Nearly every type of printing technology from inkjet printers to digital presses and offset presses, all use the CMYK print model.

You may notice that CMY is "opposite" or complementary to the RGB model. So we talk about yellow as the opposite of blue, as yellow has no blue in it. And similarly magenta is the opposite of green and cyan is the opposite of red.

It is possible to specify a color in either of these color spaces, a color can be specified by describing various amounts of RGB or CMYK. A color description could be, for example, as shown in Table 1.1, R = 10, G = 200, B = 32, on a 0–255 scale, this is a green color, and C = 23%, M = 6%, Y = 83%, and K = 4%, on a 0–100% scale, this is a yellow color.

In the case of RGB, the pixel instructions may be sent to a display, and the display implements these instructions, which results in a displayed color, Figure 1.11a. But the



(a) (b)

Figure 1.11 (a) Flat-panel displays are RGB devices as indicated by the magnified red, green, and blue screen elements. (b) A printed flyer is created with CMYK, indicated by cyan, magenta, yellow and black ink. From normal viewing distances we do not see the individual RGB or CMYK elements which fuse to create a continuous image.

same instructions sent to a different monitor, due to the differences in the display, may create a slightly different color.

In the case of CMYK, these instructions could be inking levels for an offset printing process, the printing plate would transfer, for example, the requested amount of ink onto the paper, Figure 1.11b. But if the same CMYK values were sent to a different printing process, the system may diligently obey the instructions to deposit exactly the correct amounts of ink, but obtain a different color due to the different paper, inks, and printing process it is using. *RGB and CMYK are only instructions for a device, and do not provide a reliable or precise specification of color.*

RGB and CMYK are only instructions for a device and while we can guess at the likely color these instructions will create, the final exact color will depend on the device and its configuration. So while RGB and CMYK are necessarily in units that the respective RGB and CMYK devices can readily understand, they are not really a color specification and are better referred to as instructions for a device. We say that RGB/CMYK are device-dependent color specifications, as the color created will depend on the device and its configuration.

It is OK for a user to create a file in RGB or CMYK, but it is not feasible to use RGB and CMYK when trying to communicate color information across different devices in an open color managed system.

1.8 CIE 1931 Yxy and CIE 1976 L*a*b*

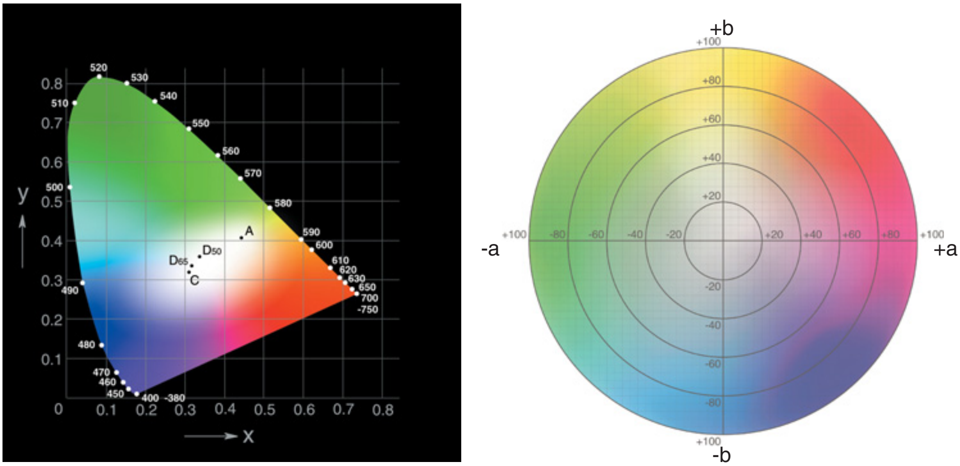
Color specification falls into two main categories: *device-dependent color* (RGB and CMYK) and *device-independent color* (Yxy and L*a*b*). A device-independent color system can be used to communicate color information among many different devices.

The Commission Internationale de l'Eclairage (CIE) defines a number of color systems that are device-independent, which means that they are based on measurement of a sample, irrespective of how it was made. The CIE systems can be thought of as a *descriptor* or *specification* of a color. Over the years, the CIE organization has specified a number of device-independent color systems; the two systems widely used in color management are the CIE 1931 Yxy and CIE 1976 L*a*b* color spaces, Figure 1.12.

The Yxy system is an older system, approved in 1931, and has a horseshoe shape, Figure 1.12a. In the Yxy system, a color is specified by its x and y coordinates on a graph called the chromaticity diagram. In the chromaticity diagram the green color takes up a large area, compressing blue and red into smaller corners.

The L*a*b* system specifies a color by its position in a three-dimensional color space, of which a two-dimensional slice is shown in Figure 1.12b. The coordinate L^* represents lightness, a^* represents the position of the color on a red-green axis, and b^* represents the position of the color on a yellow-blue axis. Notice in the L*a*b* diagram, how the colors are more evenly spaced – the green does not occupy the whole top of the diagram and the diagram has a more circular shape. In terms of color science, we say the L*a*b* color space is more "perceptually uniform".

Yxy and L*a*b* are device-independent color models that are not related to any specific device. CIE systems use an instrument to measure a color and produce a numeric result. In the L*a*b* system we may have, for example three numbers, L*a*b* of



(a) (b)

Figure 1.12 (a) The 1931 Yxy diagram is horseshoe shaped and has a large area for green colors but compresses blues and reds. (b) The 1976 L*a*b* diagram is much improved and affords all colors equal spacing. ICC color management is based on L*a*b*.

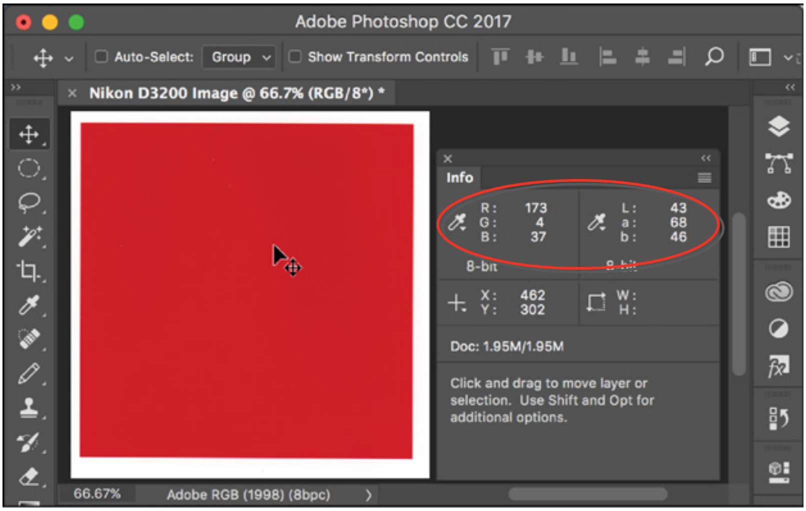
43, 68, 46 for a specific red color. A measuring instrument does not need to know about the printer that produced the sample, it just measures a printed patch. CIE systems are standardized and dependable systems, so when a color is specified by one of these systems it means the same thing to any user anywhere. The CIE color systems are described in more detail in Chapter 3, Color by Numbers.

1.9 Color Conversions

How does color management work? Under the hood, color management works by relating RGB input to CMYK output via an L*a*b* interchange. Consider an example of photographing a red object, opening the image in Photoshop, and printing the image, Figure 1.13. A simple red patch was photographed with a Nikon D3200 digital camera and is opened in Photoshop. A digital camera operates in RGB and the image is therefore necessarily in RGB. Photoshop's Info palette indicates that the cursor is on a pixel with RGB value of 173, 4, 37 (the sample is very red and so has a high R value).

Each camera has its own characteristic response, thus the RGB pixel values would be different if we used a different Nikon model, or a Canon or Sony camera. Instead of directly sending the RGB values to the printer, color management works by converting the device RGB values into device-independent L*a*b* values, as displayed in the Info palette. The camera RGB values are converted from RGB to L*a*b*, using the camera profile, in this example the profile is "Adobe RGB (1998)", as indicated in the lower part of the figure. The L*a*b* values are an unambiguous description of color and are used to convey the color requirements to a printer system. In this example, the L*a*b* values for this red are $L^* = 43$, $a^* = 68$, and $b^* = 46$.

When we print an image, the process is reversed, that is, we specify an L*a*b* value and an ICC profile determines the necessary CMYK instructions specific to each printer


Adobe Photoshop CC 2017
Auto-Select:
Group
Show Transform Controls
Nikon D3200 Image @ 66.7% (RGB/8*) *
Info
66.67%
Adobe RGB (1998) (8bpc)

R: 173
G: 4
B: 37
L: 43
a: 68
b: 46
8-bit
8-bit
X: 462
Y: 302
W:
H:
Doc: 1.95M/1.95M
Click and drag to move layer or selection. Use Shift and Opt for additional options.

Figure 1.13 ICC-aware applications such as Adobe Photoshop are able to convert RGB pixel values into L*a*b*.

to produce that color, Figure 1.14. Each printer profile receives the same L*a*b* instructions ($L^* = 43$, $a^* = 68$, and $b^* = 46$) and each profile is used to determine the appropriate amount of CMYK inks that will create this color. We see that the same red color with L*a*b* value of $L^* = 43$, $a^* = 68$, and $b^* = 46$, is created by CMYK instructions that vary by printer type. This experiment was conducted in the School of Graphic

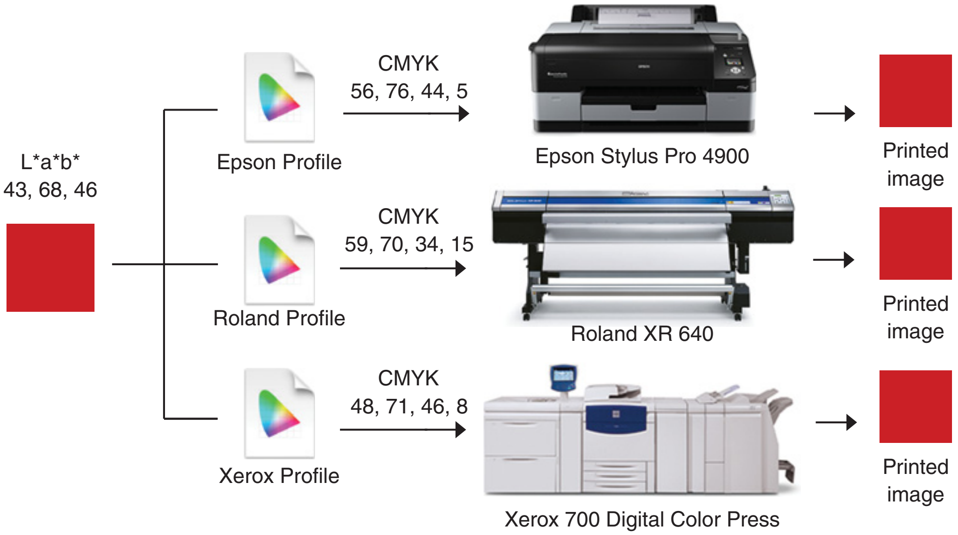

L*a*b*
43, 68, 46
Epson Profile
CMYK
56, 76, 44, 5
Epson Stylus Pro 4900
Printed image
Roland Profile
CMYK
59, 70, 34, 15
Roland XR 640
Printed image
Xerox Profile
CMYK
48, 71, 46, 8
Xerox 700 Digital Color Press
Printed image

Figure 1.14 A red image was sent to different printers at Ryerson University. L*a*b* values are converted into CMYK instructions by each device's ICC profile, such that each printer creates the same red color. *Source:* Epson and Xerox. Image from Roland DGA Corporation, reproduced with permission.

Communications Management at Ryerson University using real devices. This process "accommodates" the specific color characteristics and behavior of each individual printer.

In summary, devices can only deal with device-dependent RGB or CMYK, so images from a digital camera are necessarily in RGB and image data being sent to a printer is necessarily in units a printer can accept, i.e. CMYK. However in the middle, L*a*b* is used as a common interchange space and is used to communicate color information from source to destination all the while compensating for input device characteristics via the RGB to L*a*b* conversion, and for printer characteristics during the L*a*b* to CMYK conversion.

1.10 Three Cs of Color Management

Practical color management processes can be defined in terms of three hierarchical Cs: *calibration, characterization*, and *conversion*, as shown in Figure 1.15. Throughout this text we will make and use profiles according to three Cs of color management.

Calibration involves establishing a fixed, repeatable condition for a device. For a monitor this may mean adjusting the brightness and contrast settings. For a printer, this means agreeing on a media type and printer resolution setting. Anything that alters the color of the image must be identified and "locked-down." Calibration involves establishing some known starting condition, a means of monitoring that condition, and having the ability to return a device to its calibrated state should it drift.

After a device has been calibrated, its characteristic response is studied in a process known as *characterization*. In color management circles, characterization is commonly referred to as "profiling". During the profile generation process the color characteristics of a device are studied by sending a reasonable sampling of color patches in a test chart to the device and measuring the device's response. During characterization the color characteristics and gamut of the device are ascertained, and this information is stored in an ICC device profile.

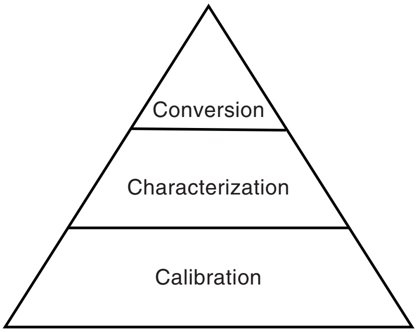


Figure 1.15 Color management operations can be described in terms of the three Cs. Calibration refers to creating a fixed baseline. Characterization refers to "profiling". Conversion happens when we use profiles to convert image data from RGB to CMYK. The calibration process should provide a solid foundation for characterization and conversion.

After a device has been calibrated and characterized, it is time to use the profiles to acquire, print, or display images. The third C of color management is *conversion*, a process in which images are converted from one color space to another using device profiles. Typically for a camera-to-printer scenario this may mean using a camera profile and a printer profile. The conversion process typically relies on application software (e.g. Photoshop), system-level software (e.g. macOS ColorSync), and a color management module (e.g. Adobe CMM).

The three Cs are hierarchical which means that each process is dependent on the preceding step. A stable calibration is the foundation of color management, that is, the device must be consistent and not drift from its original calibration. If the calibration changes this can shake the whole pyramid as the characterization becomes invalid which detrimentally affects the results of the conversion.

Nearly every color management process can be described in terms of the three Cs, therefore it is useful throughout this text to refer to operations in terms of calibration, characterization, and conversion.

1.11 Profile Types

To implement color management it is necessary to have an ICC profile for each device in your imaging chain. There are three main ways to obtain a profile for your device.

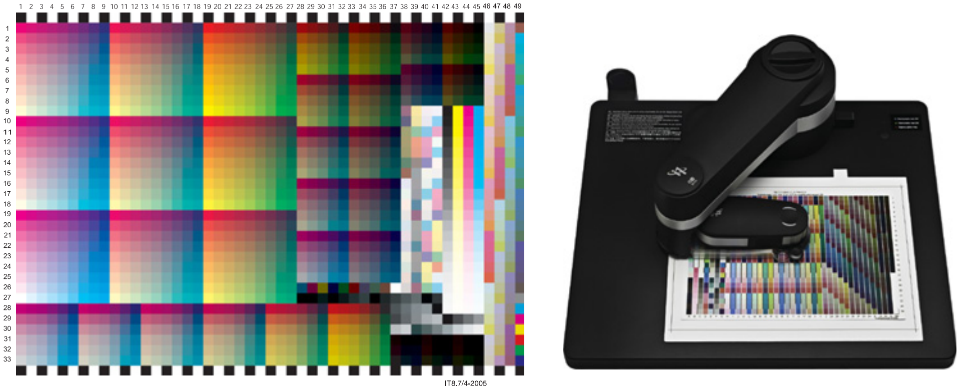
- *Custom profile*: Make a custom profile for your device using a measuring instrument, test chart, and profiling software.
- *Generic profile*: Use a generic profile as supplied by the vendor, e.g. Epson SureColor P7000 profile for use with Epson Premium Photo Luster Paper.
- *Standard profile*: Consider your device to be represented by a standardized condition, e.g. sRGB or GRACoL or FOGRA51.

Users should be aware of the different types of profile available in order to evaluate the best type of profile for a particular scenario. In general we seek a profile that is easiest to acquire, yet still delivering the accuracy and quality for the intended purpose.

1.11.1 Custom Profiles

A *custom* profile refers to a profile that is made specifically for your device and the state it is in. Creating a custom profile is what most users think of when they refer to “profiling”. Many discussions in color management circles revolve around the choice of software and hardware to make custom profiles and the nuances of the differences of a custom profile from different vendors.

The procedure to make a custom profile is based on the three Cs of color management – calibration, characterization and conversion. To make a printer profile, for example, the user *calibrates* the device, and then *characterizes* the system by printing and measuring a test chart, Figure 1.16a. Depending on the device you are profiling (an RGB printer, a CMYK printer, a multi-color printing process, etc.) there are a range of test charts to choose from. The IT8.7/4 is a chart with 1617 patches that is commonly used for profiling a CMYK printing process, Figure 1.16a. Figure 1.16b shows how the X-Rite i1iO spectrophotometer would be used to measure a test chart in order to create a



(a) (b)

Figure 1.16 (a) The IT8.7/4 is a widely used test chart for printer profiling, with 1617 patches of different CMYK combinations. (b) Custom profiles are made by measuring the test chart, using for example the X-Rite i1iO spectrophotometer. Figure (b) reproduced with permission of X-Rite, Incorporated.

custom printer profile using profile making software. *Conversion* of image data happens in a software application such as Adobe Photoshop or a printer's RIP.

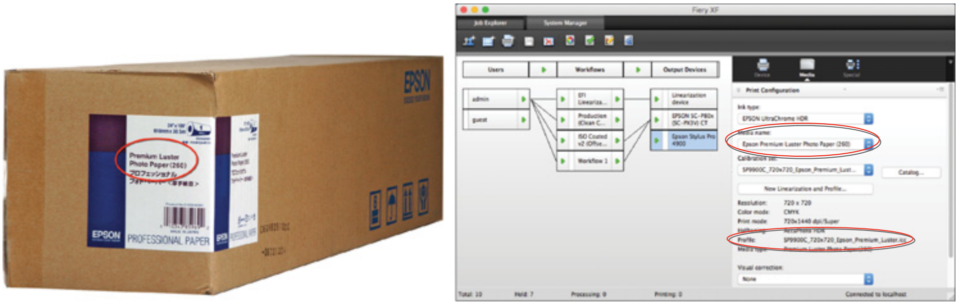
The advantage of a custom profile is that it takes into account the behavior of your specific device and the condition it is in. Custom profiling can deal with custom and non-standard media that you may wish to use. Custom profiling tends to be used for special circumstances as it requires a meticulous approach, technical knowledge, and an investment in measuring hardware and profiling software. An advantage of a custom profile is that it can fully utilize the color gamut of the device, an issue of special relevance in printing systems, that have an inherent small color gamut.

Custom profiling is an important operation in color management, and therefore custom profiling of digital camera, monitor, and printers is dealt with in separate chapters in this book (Chapters 6, 7, and 8).

1.11.2 Generic Profiles

Many inkjet and digital press manufacturers provide a *generic* profile that represents the average color characteristics of a device when printing with a specified printer model, print resolution, ink set and media. A vendor may select some representative devices from the production line to determine a generic profile. Generic profiles are typically available from the manufacturer's web site or provided within a software package, print driver, or downloadable update, Figure 1.17.

To use a generic profile, the user obtains the exact media, uses a specific printer make and model, loads the calibration file to create the correct environment, and then selects the provided ICC profile in a software dialog. Normally a re-calibration and verification may be performed to ensure the supplied profile does indeed match the local configuration. In the example shown in Figure 1.17, if a roll of Epson Premium Luster Photo Paper is used in an Epson Stylus Pro 9900 inkjet proofer, then a ready-made generic profile for this paper type can be chosen from a drop-down menu in EFI Fiery XF.



Print Configuration
Ink type: EPSON UltraChrome HDR
Media name: Epson Premium Luster Photo Paper (260)
Calibration set: SP9900C_720x720_Epson_Premium_Lust...
Resolution: 720 x 720
Color mode: CMYK
Print mode: 720x1440 dpi/Super
Profile: SP9900C_720x720_Epson_Premium_Luster.icc
Visual correction: None

(a) (b)

Figure 1.17 Out of the box, generic profiles are very convenient. A ready made profile is available within EFI Fiery XF, when using Epson Premium Luster Photo Paper with an Epson Stylus Pro 9900 printer. *Source:* B&H. Reproduced with permission of B&H Photo Video and Pro Audio.

A generic profile can be very accurate when the behavior of the printing system is well controlled, and all parameters are known. It is clear to see that use of a generic profile is very convenient as there is no need to make an ICC profile yourself, yet the user is still able to have a profile specific for their printing condition. Generic profiles are now widely used in inkjet printing and proofing and digital press devices.

1.11.3 Standard Profiles

Examples of standard profiles are sRGB, Adobe RGB, GRACoL, SWOP, etc. *Standard* profiles are ICC profiles that are based on published specifications, reference printing conditions, or international standards, and represent a convenient and practical way of managing color and communicating color information. To use a standard profile we say that a device is operating according to a standard process and then adopt a standard ICC profile for that device. If your press, for example, operates according to SWOP specifications, then in prepress and proofing, you can use a SWOP profile as your press profile, without having to create a custom profile for your press.

A number of standard profiles are available such as sRGB or Adobe RGB for RGB systems such as cameras and displays, and GRACoL, SWOP and FOGRA profiles for CMYK printing systems. Most application software and RIP systems already include standard profiles, Adobe Photoshop, for example includes a number of RGB and CMYK standard profiles. Standard profiles are readily available from public web sites such as Idealliance, FOGRA, ICC, etc.

A standard profile is a very convenient way to communicate color information, there is no need to keep track of, or wait for the printer to share a custom profile. The designer can use a public-domain, standard profile during creation of the artwork, and prepress can create a color proof using a standard profile.

sRGB is a widely used RGB profile for flat-panel displays, web browsers, and tablet and mobile devices. Like all standard profiles, the sRGB profile is based on the real response of a class of device. sRGB is based on an older monitor technology, devices that were based on cathode-ray tube (CRT) type displays. Figure 1.18a shows the three-dimensional gamut of different profiles in the L*a*b* color space. A number of different cathode-ray tube (CRT) monitor gamuts are shown. Note how they are all

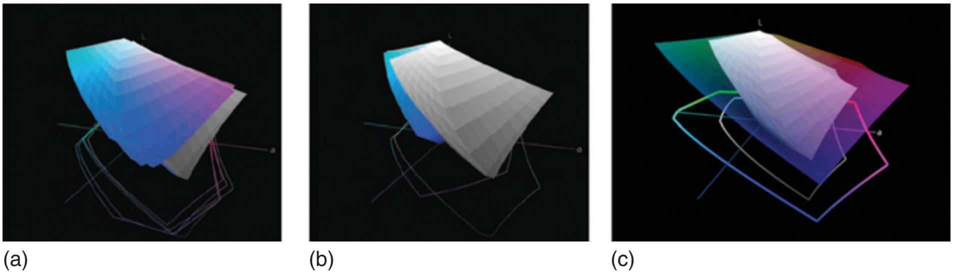

(a) (b) (c)

Figure 1.18 (a) sRGB (in gray) is based on the average of different CRT monitors. (b) sRGB gamut (in gray) is very different to an LCD flat-panel display (in blue). (c) The new Rec. 2020 profile for video and HDTV, has a larger color gamut when compared to sRGB (in gray).

very similar and how, on average, sRGB (in gray) is fairly representative of a typical CRT display. sRGB is based on legacy CRT devices, nevertheless it has now been accepted as a standard profile for many types of RGB imagery such as smartphones, tablets and Internet applications.

Using a standard profile has its limitations. Often a device may differ from a standard process. Figure 1.18b shows the response of sRGB compared to the gamut of a liquid-crystal (LCD) flat-panel display. The sRGB capability is shown as the gray volume and the LCD gamut is shown by the colored volume. The gamut of sRGB is based on CRT-type devices and is very different and therefore not representative of the response of an LCD flat-panel display. An LCD panel can display some colors, for example in the blue part of the color space.

In order to address the issue of the small sRGB color gamut, a replacement standard RGB profile is now available called Rec. 2020. The International Telecommunication Union (ITU), provides a document called a Recommendation (Rec.). Rec. 709 was first approved in 1993 and provides the chromaticity coordinates for the sRGB profile. Rec. 2020 is a 2015 recommendation for a much larger color gamut profile, as adopted by the video and broadcast industries. The Rec. 2020 RGB profile is available for use, and is provided within macOS, over time it is expected that the Rec. 2020 profile will replace the Rec. 709 (sRGB) profile as an RGB standard profile.

Standard profiles are very common in CMYK applications. A printing press is a complex machine that operates at high speed, as an example, Figure 1.19 shows a 4-color Heidelberg offset press. It is often difficult to use custom color management tools on an offset press, and we find that users are not interested in having a multitude of profiles for each individual press condition. A printing press can be operated so that it produces density/L*a*b* values that are in accordance with accepted standards for printing, known as *reference printing conditions*. Instead of profiling each individual press, it is more convenient to run a press according to a specific reference printing condition and then for the designer, prepress and proofing to use a standard profile that represents this condition.

Committees of printers, print buyers, and suppliers have worked together to develop standardized profiles based on different reference printing conditions. These datasets are based on experimental press runs, so they represent results that can be achieved in real life. There are a number of readily available standard profiles for different printing

Figure 1.19 A standard profile such as GRACoL or FOGRA51 is used to represent the color characteristics of a printing press such as this 4-color Heidelberg Printmaster 74, sheetfed, offset press. *Source:* Heidelberg. Reproduced with permission of Heidelberg®.

conditions as specified by SWOP for magazines printed by web offset lithography and gravure, GRACoL/FOGRA for commercial printing and SNAP/WAN-IFRA for newspapers. Standard profiles are invaluable in many parts of commercial printing and proofing, as discussed in detail in Chapter 8, Press and Printer Profiling.

In summary we see that users are not interested in having a long list of device profiles for every small change of paper or printing condition, and the color community has realized that as RGB devices and CMYK print processes fall into well-defined “baskets” it is more convenient and efficient to use standard profiles.

Standard profiles are realistic because they have been created from actual device data. Standard profiles are freely available for all to use, and are readily available from web sites such as Idealliance, Fogra, ICC, etc. or already installed in software, e.g. Adobe Photoshop. As long as a standard profile is a good representation of your device, it provides flexibility and convenience. An issue is that a device may be capable of a color gamut that exceeds the standard, in this instance we are losing some color ability of the device. In general we see that many users consider the efficiency and advantage of using a standard profile far outweighs the small loss in color gamut.

1.12 Color Gamuts

One of the main reasons for disappointment in color imaging is “what you see is not what you get”, in other words the printed image does not match what we saw on the screen. A

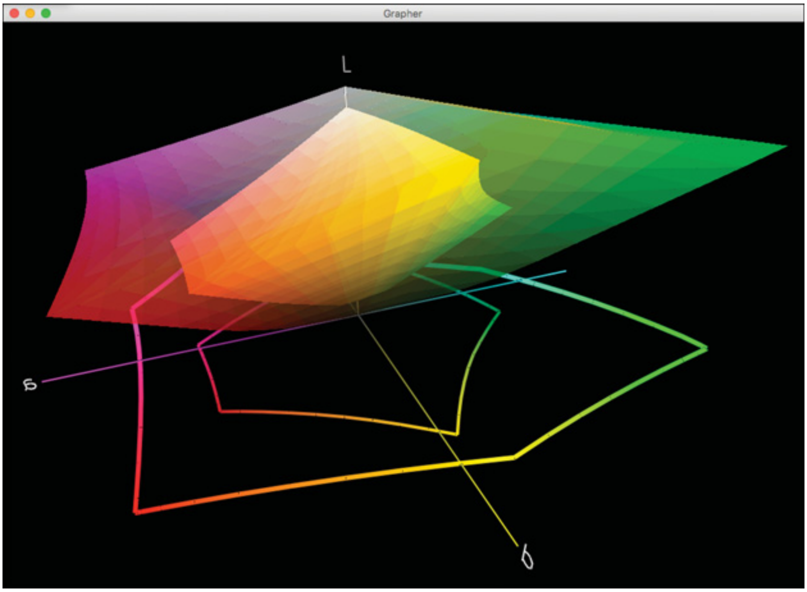


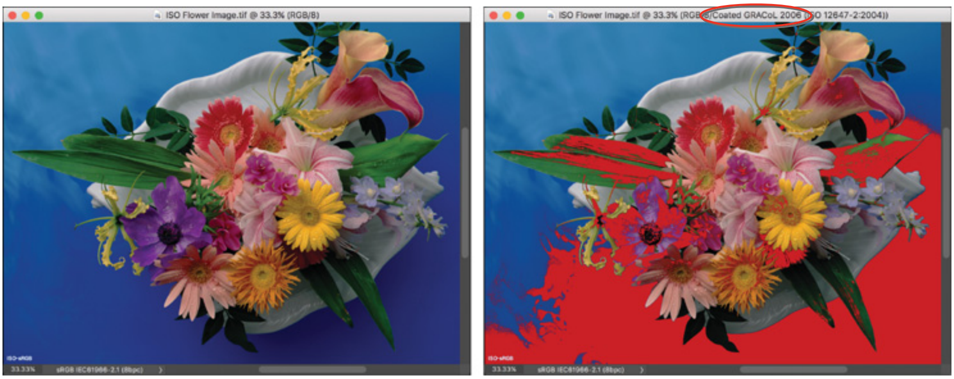
Figure 1.20 The gamut of an RGB monitor (bigger volume) is much larger than that of a CMYK print process (smaller volume), so there are many colors that may be captured by a digital camera, or that we may see on a screen, that cannot be printed.

major issue at play is differences in device color gamuts. The *color gamut* of a device is defined as the range or extent of colors a device can produce. Digital cameras, displays, and printers employ different imaging technologies and therefore have differing color gamuts. The gamut of a device is measured during the profiling process which means that profiles contain gamut information. Gamut information can be extracted from a profile and visualized in 3-dimensional software. A monitor and printer color gamut are compared in Figure 1.20.

Because imaging devices work in totally different ways (RGB or CMYK), they may not be able to create an identical range of colors. We can make a broad distinction between devices in the RGB and CMYK category. Most print processes use CMYK inks in a subtractive color imaging process, and therefore in general, printers and presses have a smaller color gamut than additive RGB color devices such as digital cameras and flat-panel displays.

Differences between the RGB and CMYK color gamuts, mean that sometimes you can see a color on your screen but your CMYK printer will not be able to reproduce that color. A digital photographer may work on a colorful set of images but the colors when printed will often be different (usually duller) to what was seen on the screen.

Due to the fundamental physics of the situation (CMYK inks that work in a subtractive imaging process creating a smaller color gamut), even a perfectly color managed process may not be able to create a screen to print match. Color management cannot eradicate the problems of gamut limitations, but it can show you what to expect. Color management helps in gamut compression by predicting and showing you the expected result. Color management allows everybody – the photographer, designer, operator,


ISO Flower Image.tif @ 33.3% (RGB/8)
ISO-sRGB
33.33%
sRGB IEC61966-2.1 (8bpc)
ISO Flower Image.tif @ 33.3% (RGB/8/Coated GRACoL 2006 (ISO 12647-2:2004))
ISO-sRGB
33.33%
sRGB IEC61966-2.1 (8bpc)

(a) (b)

Figure 1.21 The Photoshop preview mechanism uses a stain to show you which areas of the original image (a) are out of gamut of a GRACoL print process (b). Color management cannot eradicate gamut limitation issues, but it can warn you of potential problems.

customer – to see an accurate preview of the expected results, and to therefore have realistic expectations of the likely outcome.

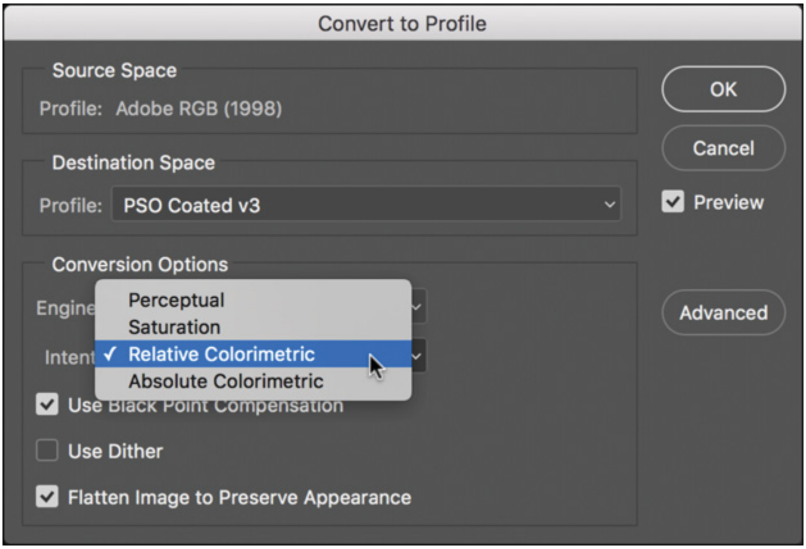
The Photoshop preview mechanism allows you to see what the image will look like on different printers or printing processes, Figure 1.21. As ICC profiles contain information about the printer's color gamut, simply by selecting the appropriate profile in color-aware software such as Adobe Photoshop it is possible to see a rendition of the printed image. You could, for example, easily see what your image will look like on a color laser printer or Epson SureColor P7000 inkjet printer or on a SWOP printing process. All of this can be accomplished without printing a single image, and you do not even need the actual printers; you only need their profiles to do this type of simulation. So color management can't solve the problem of gamut compression, but it can provide an accurate warning of which colors will be affected and in what way.

1.13 Rendering Intents

Color management provides another way to help in "managing" gamut limitations. If a color cannot be printed, a color management system helps us find the best replacement. The user can select from different approaches to finding a replacement color. The methods used to find a replacement are called rendering intents and typically the rendering intent for a color conversion is specified in application dialogs, such as in Adobe Photoshop, Figure 1.22.

The ICC has specified four standard gamut compression schemes, called *rendering intents*. The official terms for the rendering intents are perceptual, relative colorimetric, absolute colorimetric, and saturation. Let's look at rendering intents as related to different image types.

Perceptual rendering is used to process photographic-type images, as shown in Figure 1.23a. This intent processes the colors in an image so that the printed reproduction is pleasing. This process tends to alter the color from the original, and therefore there is no guarantee the reproduction will be accurate when compared to the original.



Convert to Profile

Source Space

Profile: Adobe RGB (1998)

Destination Space

Profile: PSO Coated v3

Conversion Options

Intent: ✓ Relative Colorimetric

☑ Use Black Point Compensation

☐ Use Dither

☑ Flatten Image to Preserve Appearance

☑ Preview

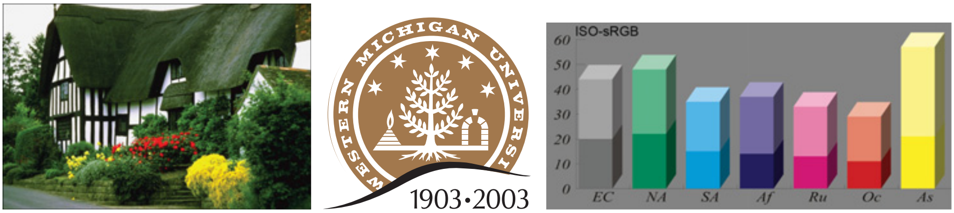
OK
Cancel
Advanced
Engine
Perceptual
Saturation
Relative Colorimetric
Absolute Colorimetric

Figure 1.22 There are four different rendering intents that the user can choose during image conversion, as shown here in Adobe Photoshop.

In fact, perceptual rendering is very likely to change the color of an image from original to reproduction. This sounds like a poor option, but in doing this sort of gamut compression, the relationship between colors is retained and this creates the best-looking and pleasing image.

The colorimetric intents are used in instances where we desire the highest accuracy in the reproduction. There are two colorimetric intents – absolute and relative. Consider a fighter plane analogy to explain relative and absolute rendering, Figure 1.24a. An F-22 fighter jet has two speeds – the speed relative to the refueling tanker and an absolute speed relative to the ground. In some situations the relative speed is important in others the absolute speed may be relevant. When the fighter jet is approaching the refueling tanker for example, their relative speed is critical.

In color management we may use absolute or relative color measurements, based on the situation. When doing a side-by-side comparison, when creating a proof for a



WESTERN MICHIGAN UNIVERSITY
1903•2003
ISO-sRGB
60
50
40
30
20
10
0
EC
NA
SA
Af
Ru
Oc
As

(a) (b) (c)

Figure 1.23 Different rendering intents are used with different types of image, (a) photographic images (b) logos and (c) business graphics.

(a) (b)

Figure 1.24 (a) The F-22 fighter jet has two speeds, a speed relative to the refueling tanker and an absolute speed with respect to the ground. *Source:* U.S. Air Force. (b) In color management we have relative and absolute colorimetry, in a side-by-side evaluation, we would use absolute colorimetry. Courtesy of David Arculus.

press run, we would normally use the absolute colorimetric intent, Figure 1.24b, however when reproducing an image across different similar media, perhaps an image in different print publications, then relative colorimetry may be appropriate.

The saturation intent makes the image more colorful by utilizing the full gamut of the destination device. This intent has total disregard for any genuine representation of color, as the precise color of the graphic is irrelevant. This intent is used for business graphics such as graphs and pie charts, for which it is important to have bright, vivid colors to make the graphic stand out and be well understood, Figure 1.23c. Because of the behavior of this intent, it is primarily used for business graphics and is not often used to process images.

The descriptions for rendering intent are generalizations. The best rendering intent will depend on the image content and the source and destination device gamuts. If you don't know which intent to use, many programs will allow you to preview your results using different intents and choose the one that looks the best. For a one line answer to "which intent should I use?", relative colorimetric rendering will be the best choice in most situations.

In summary, devices create color using different technologies, therefore each device is expected to have a different color gamut. If a device is not able to reproduce a color due to gamut limitations color management allows us to see this effect and we can use different rendering intents to direct how a replacement color should be found. Rendering intents and gamut mapping are important concepts that permeate many areas of printer color management and are discussed in more detail in Chapter 8, Press and Printer Profiling.

1.14 Color Accuracy

Color management can give you color accuracy. What does this mean? Color accuracy means that you get the colors you expect to get.

With a color management system you can scan an original, print it, and have the colors in the reproduction match the original. In this instance accuracy refers to a color match between original and reproduction.

Often we may not seek an exact "accurate" match between scene and reproduction. The colors in a red rose seen in an expansive garden setting need not be exactly the same when an image of the scene is viewed later on a laptop device. In fact an image is usually pleasing and more acceptable when the colors are different from scene to reproduction, as it is necessary to account for differences in the viewing conditions as experienced by a human observer. In this situation there is no interest in having numerical accuracy between the original and it's reproduction.

In another example, using a digital camera, it is entirely conceivable that your print process cannot reproduce all the colors that were in the original. Some colors cannot be physically reproduced by your printer. We have seen that using a soft proofing process, a color management system can show you the nearest replacement color it will use. A color managed system will then accurately print what it has shown you.

So accuracy in this situation does not refer to an exact match from original to reproduction because this is either physically not possible or is not desirable, instead accuracy means that you will get what you saw in the preview; in other words you get what you expected, there are no hidden surprises. So we can say that color management can provide color accuracy and by color accuracy we mean getting the colors you expect to get.

1.15 Late-binding Workflows

The gamut of RGB images captured from digital cameras is relatively large. If an image is converted to a printer CMYK colorspace, that has a smaller gamut, the out of gamut colors may be brought into gamut, via gamut compression. When RGB images are converted into a CMYK printer or press colorspace, this limits the images' color gamut to the gamut of the chosen CMYK process. Gamut compression is irreversible because once you have compressed the colors in the image, there is no way to get them back. Suppose you change your mind and decide not to print to that printer? Unfortunately, in this scenario it is too late; your image colors are changed forever.

A situation could occur in which an image is intended for a newspaper with a very small gamut, with the images processed accordingly. Then someone decides that the same content is to be printed in a glossy magazine or published online. The glossy magazine or an online version are capable of displaying a large color range. If the images were processed to the gamut of the newspaper they would have lost most of their colors and would not look very colorful when sent to the other output mediums.

In previous years, images would be scanned and directly converted to CMYK. In traditional color reproduction, in order to see the final result, the image was "committed" to a particular process at a very early stage. In fact it was so routine to scan images to CMYK that in some systems it was difficult to get RGB images from a scanner.

In older ways of working it was necessary to convert to CMYK in order to see the final result. In modern color management, it is preferable to retain an image in its original color space, usually RGB. In modern color management we should retain an image in its original colorspace and use ICC profiles with color-aware applications, such as Photoshop, to preview or prepare a copy of the image for different CMYK or other final output destinations. To visualize the effect of the print gamut we can simply preview in CMYK, as described earlier in Figure 1.21. And to process an image for print, we can process copies of the RGB image to different output processes only when needed and even then by using copies of the RGB image, leaving the original unchanged.

In order to retain the full color gamut of an original image, a workflow recommendation is to retain an image in its original RGB colorspace, in a so-called "RGB workflow" or "late-binding" workflow. RGB images are not committed to a print process and therefore are not gamut compressed.

Today, late-binding color management workflows happen more or less automatically, however users trained in a more conventional approach may retain the bad habit of processing content to CMYK.

1.16 Spot Colors and Proprietary Systems

Before we leave this introductory chapter it is prudent to mention some non-ICC color systems, by choosing two examples – Pantone and GMG.

There are a number of non-ICC, commercial color solutions available. These proprietary systems, however often have some connection or interface to an ICC color management workflow. Often a proprietary system will have some way of interacting with ICC programs, perhaps via sharing a common color specification, such as L*a*b*.

The Pantone system is a method widely used to specify and reproduce spot colors, Figure 1.25. In commercial printing, if a special color is required, a separate printing plate is produced containing a spot color. The actual hue of the color can be designated within the Pantone Matching System, as shown in Figure 1.25. The ink for this color is premixed and matches the swatch in the fan booklet, that the designer and prepress operator can refer to. Digital equivalents of the numbered patches are available within programs such as Adobe Photoshop and Illustrator.

Pantone and spot color reproduction is dealt with in detail in Chapter 9, Spot Colors and Expanded Gamut Printing.

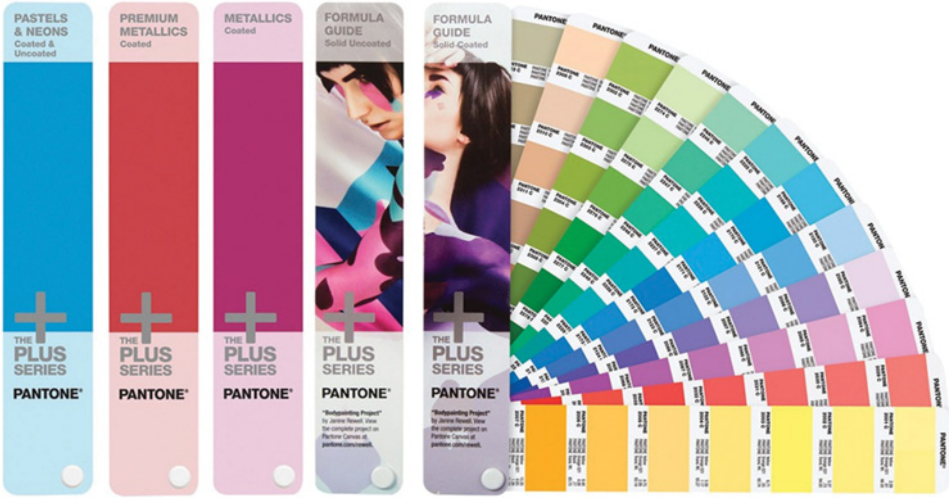


Figure 1.25 PANTONE® is a proprietary system that relies on specification of color using printed swatches in different fan books called GUIDEs. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

GMG ColorProof is a system from Germany that consists of software and output modules for various printing devices and processes. This product is a proofing and printing solution that manages color for different output processes. While the system has many features in common with the ICC system – for example, it uses an L*a*b* framework, and it uses lookup tables – it operates within its own proprietary ecosystem. It is useful for the reader to be aware that there are a number of "non-ICC" systems that may be cost-effective in different applications and specific workflow scenarios, such as spot color management or package printing.

1.17 Benefits of Color Management

Fundamentally color management allows us to match color across different devices and media, so that a Disney character, or Coke red, matches from printed advertisement to billboard to supermarket shelf.

ICC color management provides a framework that can be used to communicate color information throughout the production chain, Figure 1.26. Traditionally jobs have originated from the photographer or client, have been passed to the designer or layout department and then over the wall to prepress and finally to press. Each department works in its own silo and does not communicate color information – upstream or downstream. Problems occur when a designer, for example, chooses from an enormous palette of colors, and the press cannot hit those colors.

The ICC framework breaks down barriers allowing all participants to preview and edit and approve color. This makes sure that the customer is aware of what is, and what is not possible, there are no surprises and there are no inflated expectations, in other words, "WYSIWYG" color – what you see is what you get.

Today, efficiency in color communication is further improved through the use of an agreed ICC profile, such as GRACoL or SWOP or FOGRA. When all parties agree to design, edit, proof and print to a given profile, the designer can create a soft proof with this profile, the prepress operator can create a press proof and in the press room, the colors can be achieved on press. An ICC profile gives us an elegant container in which to store a device's color characteristics. An ICC profile is readily accepted in all software and across all operating systems.

Color management provides a number of efficiencies which save time and money. Photographers can move away from the trial and error way of working, and in terms of color, get very close, very quickly. Correct settings for ink limits and black channel generation in large format inkjet printing can offer savings for ink usage when printing

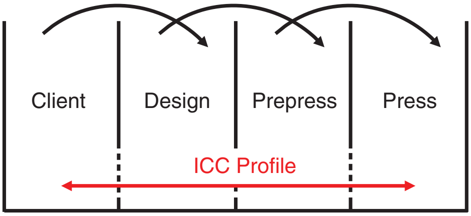


Figure 1.26 Traditionally, each part of the workflow was rigidly divided. Color management can break down traditional barriers and allow color information to be shared throughout the production process.

larger banners and signs. A color managed system allows a press operator to quickly obtain the correct color, which leads to time savings and reduced paper and ink waste.

Color management is a game changer for proofing, it is no longer necessary to use an expensive traditional proofing system, instead there is the ability to use an inkjet device to create a contract color proof. Inkjet devices do not need a skilled technician to make proofs and with a color management system a proofer can be located on-site at customer locations and remotely controlled. The cost of a contract color proof is reduced from $150 to $15.

Color management offers flexibility. Color management allows a job to be split between different devices to deliver the completed job quicker to the client, or to print locally and avoid shipping, for example in Toronto and Ottawa branches of the same company. In a recent real world example an offset press job was 100 sheets short. Instead of finding and re-mounting the printing plates the shortage was addressed via color management by printing the missing sheets on a digital press, quickly creating samples that the customer agreed were an acceptable color match.

Color management addresses the issue of the inexperienced end user. Today, color is being used in many different market segments from consumer to prosumer to full-time professional. We may say that the industry is largely de-skilled, with most users lacking a background in color theory and practice. A color management system removes the need for the user to have many years of color experience. Sophisticated color science processes are embodied within an ICC profile and may include bicubic interpolation, preferred color appearance, black and white point mapping, gamut compression, etc. The user does not need to have an understanding of these complex processes as the ICC architecture manages this behind the scenes, allowing the user to focus on image and editorial content.

Color management is a measurement-based technology, and we see that hand-held instruments such as spectrophotometers are commonly used in day-to-day operations. Humans can get tired and make different color judgements at the end of the day, compared to in the morning, in this situation a system based on instrumentation and measurement provides consistency and repeatability. A spectrophotometer rarely has different readings between the start and end of a long shift!

Numbers-based color management creates easy pass/fail instructions that remove the need for evaluation by a color expert. It is no longer necessary to do an in-person press OK. During a press OK, a print buyer visits the printer and approves the color and signs off on the press sheets for a job. In the new color management paradigm there is no longer the need to visit a remote printer location, instead simple measurement of control patches on the edge of a press sheet verifies if the numbers (and therefore the color) meets the job specifications. Via measurement of control patches there is never a discussion about whether the printed colors are within the job specification, the customer cannot refuse the shipment as all color results can be easily verified. Color management creates a protocol for remote monitoring and verification which allows non-time-sensitive jobs to be printed in China or India.

Numbers-based color management allows for pass/fail metrics that are easy to incorporate into standard operating procedures and documentation. A facility can develop a simple numbers-based tick box that allows a job to be checked and allowed to proceed. Creating and maintaining numbers-based documentation allows a facility to apply for external validation to become a “certified facility”.

Color management provides a framework for a statistical approach to managing color, measuring the performance of each device and tracking this on control charts with warning limits and action limits. Data analysis can evaluate production time vs. down time, throughput, and provide accurate data to enable equipment "end-of-life" decision making.

A color-managed system allows you to get the best color from your devices by calibrating and maintaining the device, and knowing proper controls and settings. Use of color management ensures that the device is using its full color gamut and producing good quality color. Color management provides a way to establish a good baseline and a way to get back to that baseline should devices drift.

One of the significant advantages of modern color management is that it creates the ability to buy different products from different vendors and to upgrade or replace devices with ease and convenience. Color management enables "plug and play" color. It is easy to add another device, even another type of printing technology – perhaps a laser device alongside an inkjet proofer. New devices and their software all speak the same ICC language and are all immediately up and running with no more than plugging in and calibrating.

Color management saves money as it improves productivity with less manual color adjustments, removes the need for endless iterations, and avoids late detection of costly mistakes. Color management allows a user to have a methodology to fix color issues, creates faster turnaround times, and produce work that meets customer expectations which results in happy and satisfied customers. Customers will have confidence in your work, trust that you can reproduce color accurately and consistently, be confident that they will get what they expect, and that any repeat orders will match the color of the original shipment. A facility that has a correct color implementation has organizational "color confidence", which has invaluable monetary value.

Color management is a way of working, a "philosophy", a systematic approach to color. In establishing a color managed system, you will be able to bring everyone into a common color system in terms of their understanding and working methods. You will need to educate and guide (and sometimes coerce) your customers and your employees, colleagues and your company's management.

Today color management is already part of every digital imaging system. On most systems, every image, icon, desktop, is color managed and can't be turned off. If you delete the system ICC profiles on macOS, by dragging them to the trash, for example, they are immediately replaced. Adobe Photoshop insists on an ICC profile for every image, there is no such thing as an "untagged" image. Color management is part of every digital imaging system and is difficult to turn off. As color management is already installed, there is nothing to install or upgrade, it is already there!

Color management does not require a user to write a new rule book or develop any new processes or procedures. Color management is well established and well documented, there are products, tutorials, workshops, short courses, and color consultants to assist and educate the user. The user does not need to re-invent the wheel, we have a successful ICC color management technology, tried and tested and widely accepted in every market segment, throughout the world.

After this long list of benefits of color management, one wonders how did I manage for so long? After implementation of color management most users would never look back and return to their old way of controlling color.

1.18 Summary

A fundamental issue with color imaging is that each device has its own unique characteristics. We would not expect all microwave ovens to need two minutes to cook a bag of popcorn perfectly – the devices are from different manufacturers, some brand new, some old, each appliance will need a slightly different cooking time. In the same way, in digital imaging, it is unrealistic to expect that we can just send the same image data to different devices and expect the color to match throughout.

In color imaging, in the past, a manual, closed-loop approach was used to manage color. Today however, with many different sources for images and many different destinations, a more sophisticated approach is needed.

Modern color management systems use profiles to automatically manage color across a range of input, display and output devices and systems.

Practical color management can be represented by a reference diagram, Figure 1.5 in which image data is converted into or out of, a central connection space. A number of operations were described that demonstrate the power and ability of a color management system in different capture, prepress and press environments.

This chapter described color management in terms of the three Cs – calibration, characterization and conversion. Calibration referred to establishing a fixed, measurable baseline. Characterization is more commonly known as “profiling” in which a test chart is printed and measured. Conversion is the application and use of profiles to convert image pixel data in a program such as Photoshop. Importantly it was shown that the three Cs are hierarchical, and that anything that alters the calibrated state, such as device drift, can undermine the foundation of the other processes thereby eventually reducing the accuracy of the color conversion.

Today’s color management is essentially “ICC color management”. This chapter provided an insider’s view to the ICC and its procedures, describing the current versions of the ICC Specification, and describing the work of the ICC working groups and international meetings. For the first time we have a system that is accepted and supported by the whole color and imaging community. This universal color management system puts enormous power in the hands of the end user and allows functionality that was inconceivable in older ways of working.

In this chapter we noted that RGB and CMYK are device instructions and not necessarily accurate descriptors of a color. In order to communicate color information across many different devices and systems, we need a universal way of specifying color that does not rely on a particular device and the age or condition it is in. Yxy and L*a*b* provide device-independent descriptors of color. L*a*b* is used in the Profile Connection Space at the heart of a color management system.

Color management is only possible if every device has a profile, so in this chapter, custom, generic and standard profile types were described. Traditionally most emphasis has been on making a custom profile, however the trend in recent years has been to move towards good quality generic and standard profile types.

Color gamut was defined as the range of colors a device can produce. Due to differences in the physics of the imaging process-additive vs. subtractive color synthesis-RGB camera and display devices usually have a larger color gamut compared to CMYK printing processes. It was shown that color management cannot eradicate the color changes that may occur due to gamut limitations, but it can warn you by staining the colors that are out of gamut and also allow the user to choose different rendering intents based on the content in your image.

Color management works best if you stay in the image's original color space and use simulation tools to predict the look of the image on any number of devices and thereby process copies for different destinations. Color management is most powerful in a "decide later" workflow, or a late-binding workflow. The optimum color management workflow is one in which an image is retained in its original format (with all colors) and copies are processed for various jobs.

Implementation and efficient use of color management provides a long list of benefits, including saving time, money, and materials. There are many technical, financial and customer satisfaction benefits to using color management. If used carefully and intelligently, color management works, and works very well.

This chapter has provided a general overview to the topic of color imaging and color management. In the rest of the book we provide detailed explanation for each of these concepts, in order that the reader can genuinely *understand color management*.

2

Principles of Light and Color

Objectives

- Describe the principles of color vision, including the light source, the object, and the human observer.
- Define CIE illuminants, standard light sources, and the CIE standard observer.
- Provide an explanation for color-related phenomena and processes such as chromatic adaptation, metamerism, fluorescence, color illusions, and color appearance modeling.

2.1 Introduction

It is important to understand how color works. We need to understand how devices create color and how humans perceive color. Only if we understand how color works can we control, direct, and predict processes in color management.

Practical color management refers to a number of settings, for example a "D50 light source" is often mentioned. By understanding the fundamentals of color and vision we can see why these settings are relevant. Knowing the reason we are selecting a particular setting enables us to use color management from an informed point of view. Without a genuine understanding of the underlying principles this is akin to merely following a checklist which leaves us with little ability to analyze and fix problems or adapt to new undocumented situations. The reason to understand the fundamental underpinnings of color is explained by the proverb: "… give a person a fish and you feed them for a day; teach a person to fish and you feed them for a lifetime … ." A genuine understanding of the principles of light and color enable "future-proofed" color management implementation.

Throughout this chapter we stress the fact that there are three parts to viewing color: the light source, the object, and the human observer. We specify each of these parts of the system and use this information to describe a number of different imaging scenarios.

We begin this chapter by looking at what light is. Light is the basic tool in imaging. It is the messenger that leaves a source, picks up information about an object, and delivers it to the eye to be processed. Light is a form of radiation that constitutes the visible part of the electromagnetic spectrum. There are many types of light sources. Some are artificial and some are natural sources, like daylight. We look at how to specify the characteristics

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of a light source. The CIE provides a number of standards for all aspects of imaging. In this chapter CIE illuminants, standard light sources, and the CIE standard observer are defined.

Next, we look at specifying the color of an object, such as an apple. We describe the concept of the spectrum and show how it can be used to predict object colors in many situations. We consider the effect of changing the illuminant and explore important phenomena including chromatic adaptation and metamerism.

The final sections of this chapter are devoted to a discussion of color, vision, and measurement. A situation that can prejudice a color management system occurs when the border surround affects the perceived color of a sample. Some well-known color illusions are used to explain and demonstrate this effect.

The principles explored in this chapter relate to many practical color management applications discussed in later chapters.

2.2 Light Source – Object – Human Observer

There are three things that affect the color of an object. This interplay of factors is shown in Figure 2.1. First, there is the *light source* that is shining on the object. If the light is very yellow, it will make the object look yellow; if the light is blue, it will make the object look blue. Next, there is the *object* itself. Different objects (e.g. a red apple or green grass) reflect different parts of the incident illumination. An object reflects or transmits different parts of the incident light, and this puts a unique "color imprint" on the light leaving the object's surface. Finally, there is the interpretation of this information in the eye–brain system of the *human observer*. Light from the object arrives at receptors in our eyes, and this information is conveyed to our brain, where it is interpreted as a sensation of color and thus we "see," for example, the red apple.

We stress the fact that there are three parts to viewing color: the light source, the object, and the human observer. We see that to be successful, a color management system must take into account these three aspects of viewing color.

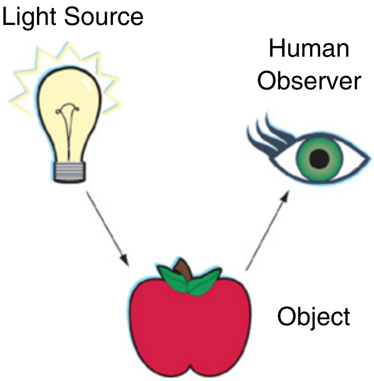


Figure 2.1 The color of an object depends on the light source, the object, and the human observer.

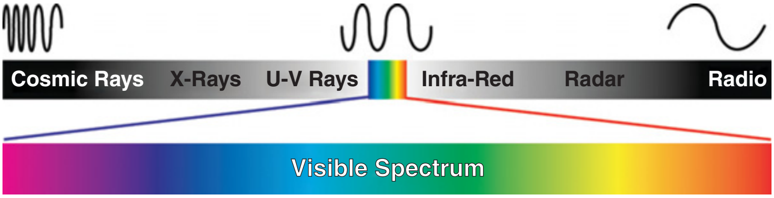


Figure 2.2 The spectrum consists of waves of different length. Humans are sensitive to only a small part, known as the visible spectrum. On either side of the visible spectrum are ultraviolet and infrared waves. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

2.3 Electromagnetic Radiation

We now consider light and light sources. Light is the basic tool in imaging, so, what is light? Light is generally considered to be a wave and is described in terms of the length of that wave, Figure 2.2. Light is not the only type of wave; there are a whole range of waves from cosmic rays (such as gamma radiation from high-energy astrophysical events), X-rays (used for medical purposes and airport security), ultraviolet rays (emitted by lamps in tanning beds), infrared, radar, microwaves (used in microwave ovens), radio, and TV waves. Collectively, these waves form the electromagnetic spectrum. The human eye can perceive only a small fraction of the available wavelengths. The small region that humans are responsive to, is called the visible spectrum. *Waves that constitute the electromagnetic spectrum are referred to as radiation, in the visible region that radiation is known as light.*

The spectrum is divided and labeled according to the length of the waves (i.e. wavelength). X-rays are very short waves and are microscopic in size. Infrared waves are about the size of a pinhead, and radio waves can be as long as 3 meters. Because the waves vary so much in size, it is convenient to use different units of length for different parts of the spectrum. For waves in the visible part of the spectrum, it is normal to use units of nanometers (nm). A nanometer is 10^{-9} m (one thousand millionth of a meter).

2.3.1 The Visible Spectrum

Our eyes contain light-sensitive cells that respond to particular wavelengths. When light waves strike cells in our eyes a message is sent to the brain. The brain interprets this signal and we perceive a color. The color we see depends on the wavelength of light that enters our eye. Wavelengths making up the visible band start at about 400 nm and end around 700 nm. Below 400 nm is the ultraviolet region, and above 700 nm is the infrared region. Waves outside the 400–700 nm range do not trigger any response in our eye/brain system, and we say that these waves are invisible to us.

We know from experiments that when wavelengths from 400–500 nm enter our eye these are perceived as blue. Light waves in the region of 500–600 nm create an impression of green, and waves between 600 and 700 nm are seen as red. This division is an approximation and is described here as a convenient way to remember the main parts of the spectrum. In fact, the visible spectrum is a continuum containing the colors of the rainbow. Starting from 400 nm, we would see violet, indigo, blue, green, yellow, orange, and red (at about 700 nm), Figure 2.2. The rainbow has this sequence of colors, and the colors form the abbreviation – VIBGYOR, or known backward, by the school yard mnemonic of "Richard Of York Gave Battle In Vain." If the eye is presented with all these wavelengths at once, we see this as white light. It is important to note that the waves themselves are not colored, and *color is not a physical entity, rather the interpretation of the waves in our eye/brain imaging system produce a sensation that we call color*.

2.4 Specifying the Light Source

Let us look at sources that emit radiation in the visible part of the spectrum. Light can come from many natural and artificial sources. Natural sources may include sunlight and clear or cloudy sky. Artificial sources may include candles, tungsten lamps, electronic flash, fluorescent lighting, LED sources, and sodium-vapor street lamps.

The perception of color occurs when light travels from the light source, reflects off an object, and arrives at our eye. We can only perceive something if there is some source illuminating what we are looking at. That is, for example, we need to turn the light on in a darkened room before we can perceive any colors. However, light sources do not merely illuminate the scene. Light sources have a color of their own, and the color of the light source influences the color of the sample. Therefore, what we finally perceive is a combination of the color of the light source *and* the color of the sample.

2.4.1 Spectral Power Distribution

Light sources can have very different operating principles which results in a wide variation in the color of the light from the source. The color of light from a source can be described in terms of the relative amount of light it emits at each wavelength. This is plotted as the relative power at each wavelength and is technically known as a *spectral power distribution curve*. Figure 2.3 shows the spectral power curves for a number of light sources. Underneath each plot is a color bar indicating the wavelength–color relationship.

The spectral plots show us the amount of output from these sources at each wavelength. We see that these sources are very different in terms of the amount of energy they have at each of the wavelengths. Let's see how to interpret these plots and thus see what they tell us about the characteristics of the light source and the effect this may have if they are used to illuminate an object.

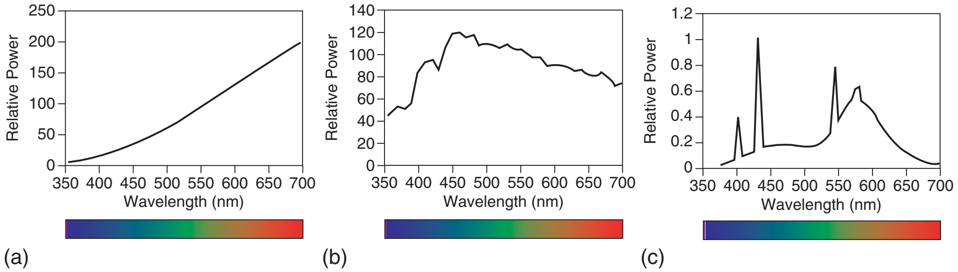


Figure 2.3 (a) Tungsten sources are very smooth and very red, (b) daylight is very neutral, and (c) fluorescent sources often have a very spiky response.

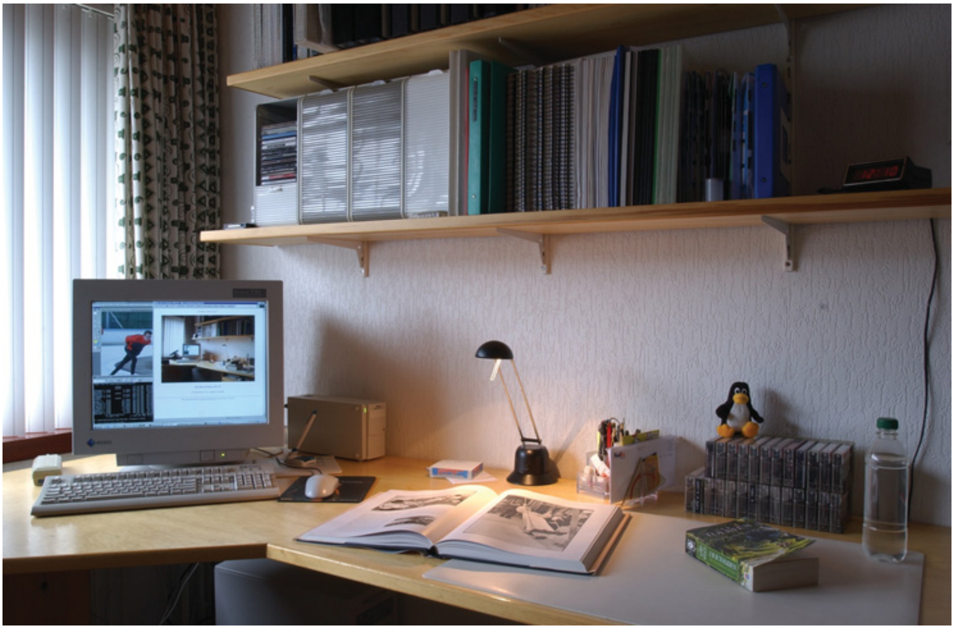


Figure 2.4 Near the window, daylight is fairly neutral, the computer monitor is very blue, and the tungsten desk lamp is yellow. Objects viewed near each source are affected by the color of the source. Courtesy of Patrick Hudepohl.

The tungsten source, Figure 2.3a, emits an increasing amount of energy in the red part of the spectrum. Daylight, Figure 2.3b, tends to be well balanced with emission throughout the spectrum and thus the "color" of this source is more or less neutral. A fluorescent light source, Figure 2.3c, has some dominant peaks in the blue and green part of the spectrum – the illumination from this source is very spiky.

From the graphs it is clear that each source has very different characteristics and thus they are likely to have different effects on a sample. For example, if you view a white sheet of copy paper under tungsten light it will look yellow, whereas if you walk quickly to a window in daylight it will look relatively neutral, and on holding the same sheet of paper up to a fluorescent light, you may perceive a blue cast.

You can notice the effect of different light sources in practice, as shown in Figure 2.4. For example, daylight is fairly neutral, the computer monitor is very blue, and the tungsten desk lamp is yellow. It is useful to have a way to practically demonstrate the influence of the color of the light source, to do this we may want to use a specially constructed viewing booth, Figure 2.5.

The color of the source is one consideration, another consideration is the smooth continuous nature of some sources (incandescent, daylight) vs. the spiky response of others (fluorescent lamps). The spiky nature of fluorescent sources becomes relevant in color management, especially when these sources are used in viewing booths.

In summary, the role of the illuminant should not be underestimated during the evaluation of color. *We should always keep in mind that the color of a sample can change depending on the light source it is viewed under*, so in color management we must pay

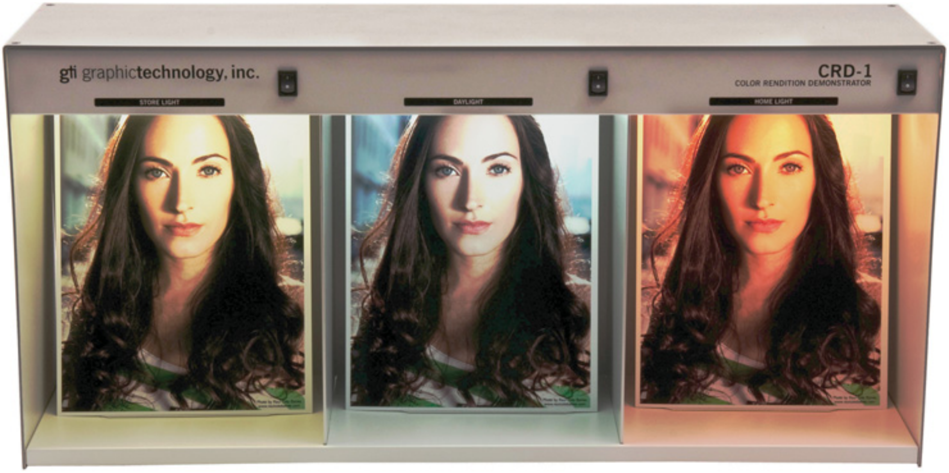


Figure 2.5 The GTI Color Rendition Demonstrator shows the dramatic effect of different light sources on an identical print. *Source:* GTI. Reproduced with permission of GTI.

attention to selecting and using appropriate light sources. By knowing and properly specifying the light source we can accommodate a wide range of different sources.

2.4.2 Color Temperature

It is important to be able to communicate information about the light source so we know what type of light we are using and what light other users or our clients are using. The spectral power distribution curve, described in the last section, provides a complete and accurate form of expressing the quality of light from a source, but it is not the most convenient form to use.

Although it is technically accurate to specify a light source by its spectral power distribution graph it is not immediately obvious from the graph what "color" the light source actually is. It is also difficult to communicate information as a graph. If you wanted to describe the color of your light source to somebody else, you would have to send them the entire graph. In addition, even if you are presented with two slightly different spectral graphs, it is not always possible to discern whether the lights are a different color or not.

There is another, more convenient way of describing the color of a light source. This is called the *color temperature* scale. The system is based on an area of physics that deals with Planckian (after German physicist Max Planck) "black body" radiators. The idea of color temperature can be appreciated by considering the progressive heating of a piece of metal. As objects are heated, they get hotter and begin to glow and emit light. The color changes as objects get warmer, so an object goes from dull black to deep red then bright red and finally to "white hot." It is therefore possible to describe the color of a light source by temperature. When used in this way, the temperature is called *color temperature*.

Color temperature is measured on an absolute temperature scale that has units in Kelvin (K). For example, a tungsten source may have a color temperature of 2800 K.

(No degree sign is used with K, so color temperatures are not written as 2800 °K but simply 2800 K.) Typical values for common light sources are: high-pressure sodium vapor (used for night-time street lighting), 2100 K; photographic studio lamp, 3400 K; electronic flash, 6000 K; average daylight, 6500 K; artificial daylight fluorescent lamp, 6500 K; uncalibrated computer monitor, 9300 K. In the color temperature scale, lower color temperatures are redder and higher color temperatures are bluer. *The color temperature scale provides a succinct, numerical means of specifying the color characteristics of a light source and is widely used in color management.*

Tungsten bulbs are incandescent materials containing a filament through which an electric current is passed, causing the element to get hot and radiate light. Tungsten lamps operate in the manner intended by the color temperature scale, and the color of the light can therefore be assigned a color temperature value. Other sources, such as fluorescent lights, are not heated up and therefore do not operate this way. These lights contain a gas that is excited by the discharge of an electric current, which in turn excites the phosphor coating of the tube, which glows, giving off light. (The chemical composition of the coating can be altered to adjust the color temperature of the emitted light.) The color temperature scale is based on lights that operate the first way; that is, generating light by heating a material. In fluorescent lights or LED sources, no material is heated to the point where it glows. For cases in which a light source is not heated to produce radiation, we can still quote a color temperature for that source. In these cases, the correct term is *correlated color temperature*. The color temperature of a non-heated light is derived by comparing it with the spectrum of a heated lamp. In common usage, the word *correlated* is often dropped and the color temperature of all light sources (incandescent or not) is stated in Kelvin.

2.4.3 CIE Illuminants and Standard Sources

We have already noted that it is useful to be able to specify and communicate information about a light source. A further requirement is that a few light sources be chosen and adopted as universally accepted standards. Periodically over the years, in response to user needs, the CIE agrees on the name and specification of an illuminant and publishes the spectral power graph for the color community to implement.

A *CIE illuminant* is a theoretical spectral power curve that has been established as a standard. The spectral curve can be an average of light sources and may or may not be a real, actual light source. Vendors are free to produce *sources* (real lamps) with spectral plots that correspond to a specified illuminant. If a real lamp corresponds to one of the defined illuminants, it is known as a *standard source*. In summary, we say that an *illuminant* is a theoretical spectral power curve adopted as a standard, whereas a *source* is an actual light that may approximate one of the illuminants.

Over the years, the CIE has defined a number of illuminants, Table 2.1. Illuminant A is represented by incandescent lights (tungsten filament bulbs). These devices have a color temperature of 2856 K. Illuminants B and C are daylight-type illuminants, but they are no longer in general use. They were made by placing a liquid cell containing a blue copper sulphate solution in front of illuminant A. D illuminants are daylight-type illuminants. Illuminants D50, D55, D65, and D75 have color temperatures of 5000 K, 5500 K, 6500 K, and 7500 K, respectively. D50 and D65 are widely used as illuminants in printing, imaging, and color management. D50 is favored in North America while

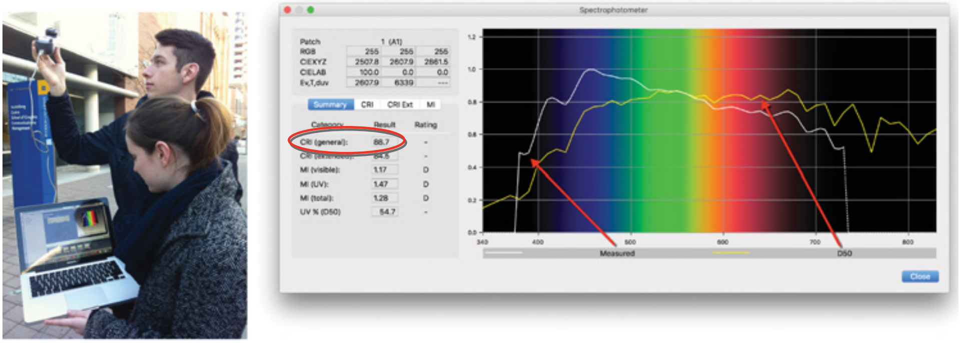
Table 2.1 CIE illuminants, corresponding light sources, and their color temperature. Lower color temperatures represent warmer (redder) light sources, higher temperatures correspond to sources that are more blue.

CIE Illuminant	Type of light source	Color temperature
Illuminant A	Tungsten lamp	2856 K
Illuminant B*	Direct sunlight	4874 K
Illuminant C*	Overcast sky	6774 K
D50	Direct sunlight	5000 K
D55	Sunlight with skylight	5500 K
D65	Overcast sky	6500 K
D75	"North sky" light	7500 K
Illuminant E	Hypothetical equi-energy illuminant	5400 K
Illuminant F	Fluorescent lights	Various
-	Uncalibrated computer monitor	9300 K

*Illuminant B and C are no longer in use.

European countries often use D65. Illuminant E is an imaginary, hypothetical equi-energy illuminant. Illuminant E consists of equal power per wavelength across the visible spectrum – that is, the spectral power distribution curve is a horizontal line. Illuminant E is used in some colorimetry calculations. Series F illuminants are realized by fluorescent lights.

It should be noted that the spectral power distributions for standard daylight are typical, average values, so that any actual sample of sunlight, might be slightly different to the D illuminants, according to the geographic location, altitude, weather, time of day, and so on. Nevertheless, it is remarkable how close a daylight measurement can be, compared to CIE Illuminant D50, Figure 2.6. The results show a high Color Rendering Index (CRI) of 88.7, indicative of a close similarity between a real measurement and theoretical D50.



Patch	1 (A1)		
RGB	255	255	255
CIEXYZ	2507.8	2607.9	2861.5
CIELAB	100.0	0.0	0.0
Ev,T,duv	2607.9	6339	----

Category	Result	Rating
CRI (general):	88.7	-
CRI (extended):	84.5	-
MI (visible):	1.17	D
MI (UV):	1.47	D
MI (total):	1.28	D
UV % (D50)	54.7	-

(a) (b)

Figure 2.6 (a) Daylight was measured on an April afternoon in Toronto, Canada. (b) The results show a high CRI of 88.7, indicative of a close similarity between the real measurements and D50.

2.4.4 Viewing Booths

D50 is one of the most commonly used color temperatures in color management. If somebody holds up a print and says they do not like the colors, the first thing to do is to ask them how are they viewing the print? If color measurement and evaluation for the print was done with settings that intended viewing for D50, the sample should be viewed under D50. The print is only intended for a specific viewing condition and may look different under other light sources. Another way to think of this is that if you have sent a print to your client and you want them to see what you see, they must view the print under the conditions you viewed and measured it under.

One way to create well specified and controlled viewing conditions is to use a viewing booth, as shown in Figure 2.7. Viewing booths will have switches that offer D50, D65, or other illuminant conditions.

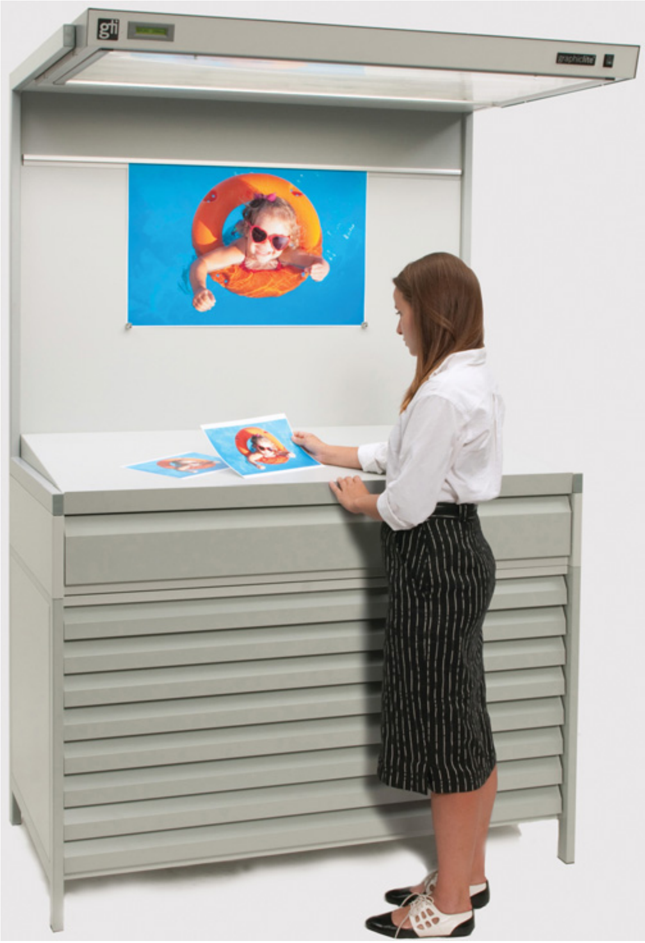


Figure 2.7 Viewing booths are used to create standard viewing conditions and are a vital part of a color management system. North American manufacturer GTI's EVS-3052 model shown here. *Source:* GTI. Reproduced with permission of GTI.

Figure 2.8 Food looks most appealing when shown as yellow colors with warm lighting.

The relevance of the light source cannot be over-estimated – it can have a huge impact on viewed colors. It is extremely important to establish standard viewing conditions and to pay attention to the light source and the viewing environment. Strictly speaking there is no “correct” light source for viewing a print. What is more important is that *we know the light source we are using and that the light source is what it says it is.*

2.4.5 “Warm” and “Cold” Colors

Associated with the description of an illuminant and the color temperature scale is another qualifier to describe the color of a light source (and also colors in general). It is possible to talk about warm and cold colors. *Warm* colors have a lower color temperature, and *cold* colors have a higher color temperature. It is interesting to consider the relationship between our perception of color and the feeling it creates.

If a room is painted with warm colors (red, yellow, or orange) we find this inviting and comforting. A blue room will look and feel cold; it will not be cozy. There are other relationships between color and how we feel. The next time you see an advertisement for food look at the color scheme. Food is predominantly shown in warm colors, see for example Figure 2.8. A loaf of bread with a blue cast would not be appealing. The qualitative terms “warm” and “cold” are often used in color management circles, for example, to describe a light source, the look of a monitor display, or the color cast in a printed image.

2.5 Measuring the Sample Spectrum

In the last section we saw how to describe the light source. This section considers ways of describing the color of the object itself.

One way of specifying the color of an object is by its spectrum. A spectrum can be plotted for all objects and is a very useful and complete description of an object’s color characteristics. The spectrum can be used to explain a host of color-related issues.

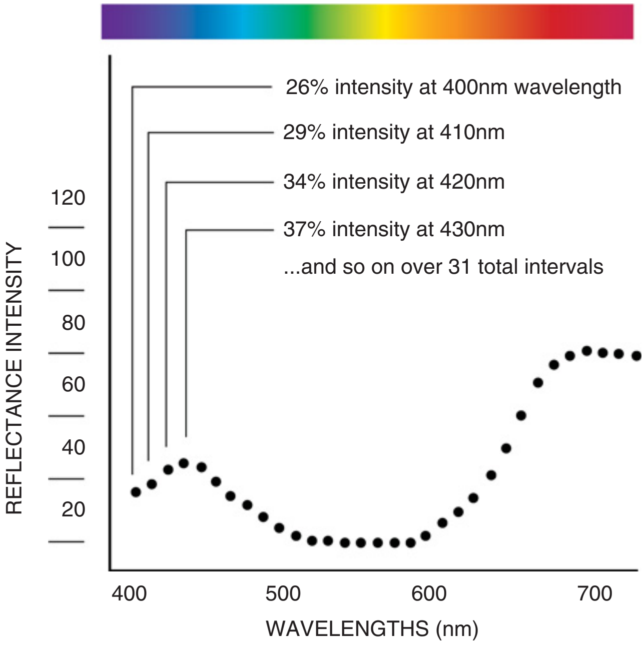


Figure 2.9 The spectrum is a plot that shows the percentage of light at each wavelength that is reflected by a sample. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

For example, it explains why an object appears a particular color, and it can also be used to explain a phenomenon called metamerism. The object spectrum also forms the basis for CIE color measurement calculations, as described in Chapter 3, Color by Numbers.

The *spectrum* is a graph of an object's reflectance (or transmission) at each wavelength, Figure 2.9. When an object is illuminated with light containing different wavelengths, the object absorbs some light and reflects some back. The spectrum is a plot of how much light is reflected back from the object, compared to how much was incident on the object. An instrument can be used to measure (at each wavelength), the amount of light reflected back from an object.

2.5.1 Practical Color Samples

Let's look at some typical spectral curves, examples of which are shown in Figure 2.10. The spectral plots show us how much of light at each wavelength is reflected by the material. For a blue sample, we note that most of the wavelengths are reflected in the 400–500 nm range. We perceive radiation in this part of the spectrum as blue, and thus this sample appears blue to the human observer. Similarly, a green patch reflects mainly in the middle part of the visible spectrum (500–600 nm), and a red patch reflects toward the end of the visible spectrum (600–700 nm). Note that the spectra are not "ideal." That is, the blue spectrum, for example, does not start and end exactly at 400 and 500 nm. In practice, very few colors are "perfect" in this sense.

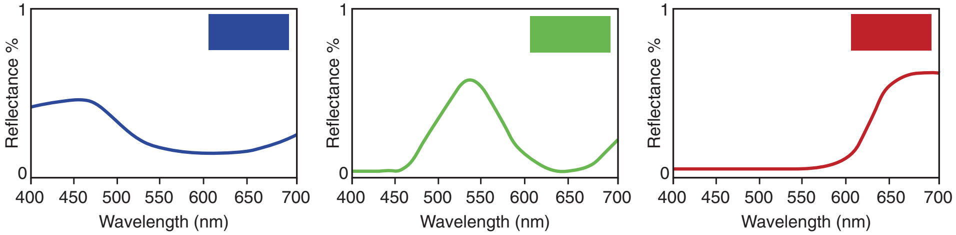


Figure 2.10 Objects with reflectance between 400–500 nm appear blue, 500–600 nm appear green and 600–700 nm appear red. Note that blue, green and red objects rarely have spectra exactly at the 400, 500, 600 nm demarkation, as shown in these real measurements.

It is possible to determine the *reflective* spectrum for printed samples and the *transmissive* spectrum for images viewed in transmission, such as film transparencies, as shown in Figure 2.11. In transmission, some of the incident wavelengths are absorbed, and those that get through the material form the transmission spectrum. It is possible to plot the spectrum for *emitted* colors as well, such as colors formed by a flat-panel display. When we profile a monitor it is possible to turn on each color group in turn and thus measure the characteristic spectrum of the red, green, and blue elements.

In practical color measurement, if you have a measuring instrument called a spectrophotometer, you can use it to measure and store the sample's spectrum for each patch of a color target, as shown in Figure 2.12.

A spectrophotometer measures the spectrum wavelength by wavelength. The instrument records what percentage of light at each wavelength is returned by the sample. A light internal to the instrument is used to make this measurement. In general, a D50 or D65 illuminant would be used to provide broad wavelength coverage. However, the actual source used in the instrument is irrelevant and not considered in the calculation of the object spectrum. All we are doing in a spectral measurement is measuring the *percentage* of the light reflected back at each wavelength. Thus, if we expose the sample to 40 units of light and we get back 20 units of light the reflectance at this wavelength is 50%. An important feature of the spectrum is that it forms a description of the object *independent* of the illuminant. There is a big advantage to measuring the sample without the influence of any light source. If we know the characteristic of the sample it is easy to

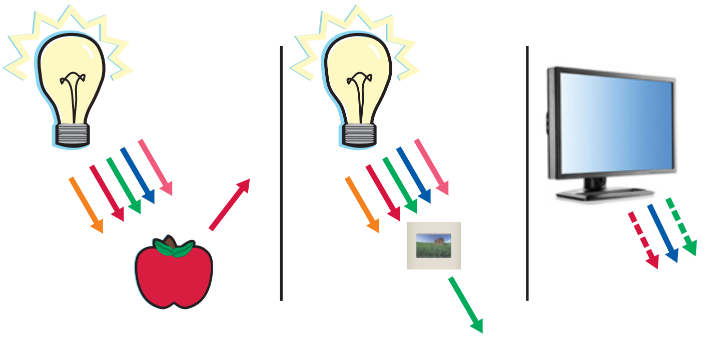
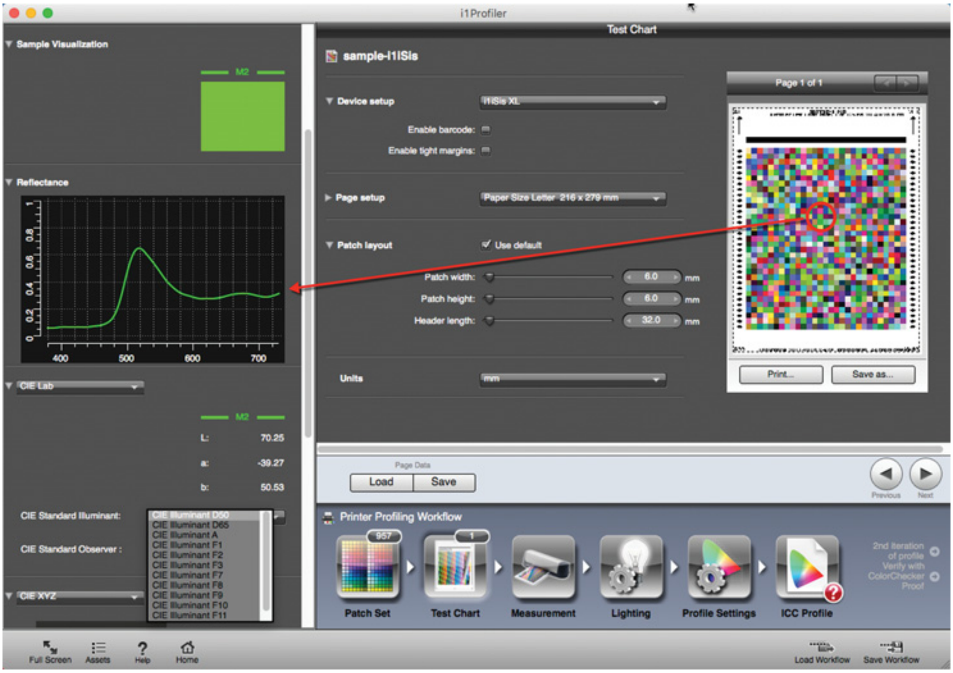


Figure 2.11 It is possible to measure the reflected, transmitted, or emitted spectrum of a sample.


i1Profiler
Sample Visualization
M2
Reflectance
1
0.8
0.6
0.4
0.2
0
400
500
600
700
CIE XYZ
Test Chart
Page 1 of 1
Print...
Save as...
Page Data
Load
Save
Previous
Next
Printer Profiling Workflow
957
1
Patch Set
Test Chart
Measurement
Lighting
Profile Settings
ICC Profile
2nd iteration of profile
Verify with ColorChecker Proof
Full Screen
Assets
Help
Home
Load Workflow
Save Workflow

CIE Lab

M2

L: 70.25

a: -39.27

b: 50.53

CIE Standard Illuminant: CIE Illuminant D50

CIE Illuminant D65
CIE Illuminant A
CIE Illuminant F1
CIE Illuminant F2
CIE Illuminant F3
CIE Illuminant F7
CIE Illuminant F8
CIE Illuminant F9
CIE Illuminant F10
CIE Illuminant F11

CIE Standard Observer :

sample-I1ISis

Device setup: I1iSis XL

Enable barcode: ☐

Enable tight margins: ☐

Page setup: Paper Size Letter 216 x 279 mm

Patch layout: ☑ Use default

Patch width: 6.0 mm

Patch height: 6.0 mm

Header length: 32.0 mm

Units: mm

Figure 2.12 X-Rite's i1Profiler software allows you to measure a printed test chart using a spectrophotometer and then by clicking on each measured patch the program graphically display the sample's spectrum.

add to this the effect of any light source we want and to be able to predict the new color of the object under that source.

The spectrum is the most complete and unambiguous representation of a sample's color. The spectrum fully specifies the color of a sample and it is used to calculate color metrics such as L*a*b*.

2.6 Quantifying Human Color Vision

In the previous sections we defined the spectral response of the light source and the sample. Now we get to the final part of the process, the human observer. In this section we describe the role that the human visual system plays in color perception.

We have seen that it is possible to describe lights and objects in terms of their spectrum. In essence, the human eye also has a "spectral response." The spectral response curves of the eye help us understand how humans see color and this helps us construct and implement color imaging systems.

When radiation reaches the eye it is detected by sensor cells that register the information and send it to the brain for processing. The eye has two types of receptor cells, rods and cones. Rods are used in low light level situations such as at night-time, and they only see in "see" in black and white. This is why at low light levels everything appears monochromatic or devoid of color. As the viewing environment gets brighter, the rods cease to function and the cones take over. Cones are responsible for color vision.

There are three types of cone cells, each sensitive to the red, green, or blue part of the spectrum.

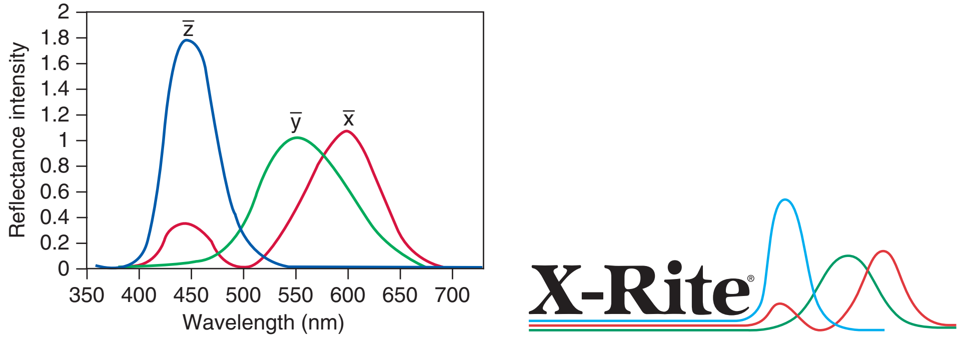
Another aspect of the human visual system is that because part of the human visual process relies on interpretation we are never quite sure exactly what "color" each person's eye-brain system will see. If we devised an experiment in which we arranged for the same wavelength of light to be shown to different observers we would not be sure if they all saw the same color. We could expect everybody with normal color vision to have a similar experience of color, but this could vary slightly from person to person, and may even vary within an individual (the change occurring as they get older, for example). What would be useful is a set of response curves that are an average of the population that can be used to describe the human observer. This requirement is provided by an "idealized" human observer called the CIE standard observer.

2.6.1 CIE Standard Observer

To contend with the issue of all observers seeing color slightly differently the CIE developed the concept of the *CIE standard observer*. The standard observer is a mathematical way of representing the average color vision of the human population.

The CIE used three specific primary colors and conducted experiments to work out how much of each of these primaries would be needed to match colors in the spectrum. In 1931, the CIE published the results of these experiments as graphs called the *color-matching functions*. These functions are shown in Figure 2.13a. The color-matching functions can be thought of as functions that represent the color response of the average human observer. The color-matching functions are designated $\bar{x}$, $\bar{y}$, and $\bar{z}$, (pronounced "x bar, y bar, z bar"). The interpretation of these graphs is that they show how much of each primary is needed to make the color represented by each wavelength.

The CIE makes a significant contribution to the whole area of color measurement by providing data for the color characteristics of an average human observer. Without this information it would be very difficult to account for human vision within software, instruments and color calculations. Using the color-matching functions the



(a) (b)

Figure 2.13 (a) The CIE color-matching functions, $\bar{x}$, $\bar{y}$, and $\bar{z}$, provide a way to represent the color vision of the human observer. X-Rite recognized the significance of these graphs and used them as the basis for their former corporate logo.

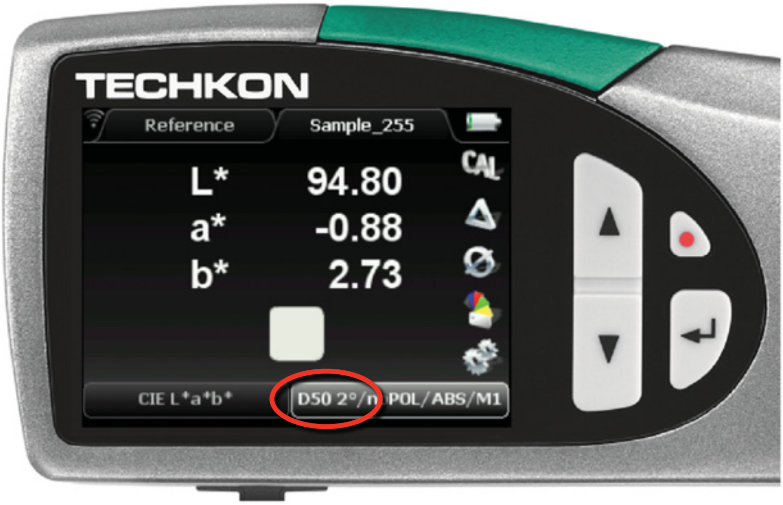


Figure 2.14 Most color measurements will be calculated with reference to D50 and the 2° standard observer, as seen here in the Techkon SpectroDens instrument display.

measurement of color is derived from purely physical data (easily measured spectrophotometric data) and is based entirely on instrumental measurement.

X-Rite is a major manufacturer of color-measuring instruments and recognizes that a large part of their business relies on the usefulness of the CIE color-matching functions. The color-matching functions are so important that X-Rite used them in the past as part of their corporate logo, Figure 2.13b.

In 1931, the CIE experiments for deriving the color-matching functions were conducted at 2° (two degrees). The angle refers to the angle formed at the eye by an object at normal viewing distance from the observer. 2° is the angle of view created when viewing a monitor or print, so in color management it is normal to use tables corresponding to the 2° standard observer, Figure 2.14. As we view small areas of color somewhat differently than larger areas of color, in 1964 the experiments were repeated at 10° (ten degrees). The 10° observer may be appropriate when, for example, viewing a painted wall. Thus there are two data sets, one for the 2° (1931) standard observer, and the other for the 10° (1964) standard observer.

2.6.2 Trichromatic Vision

Human color vision is based on the cone cells in our eyes, these cells are sensitive to specific red, green, and blue wavelength regions. During the process of "seeing," the cones sum up or averages the light incident on them. The blue cones respond to light in the range 400–500 nm, and the green and red sensitive cones respond to light in their part of the spectrum. The cones integrate the incident wavelengths and reduce the entire spectrum of incident light to just three signals, one for each of the cone types. As any incident spectrum is effectively reduced to only three signals, *samples do not have to have identical spectral properties in order to appear as a color match to the human observer*. Two quite different spectra can create the same cone stimuli, resulting in colors that appear

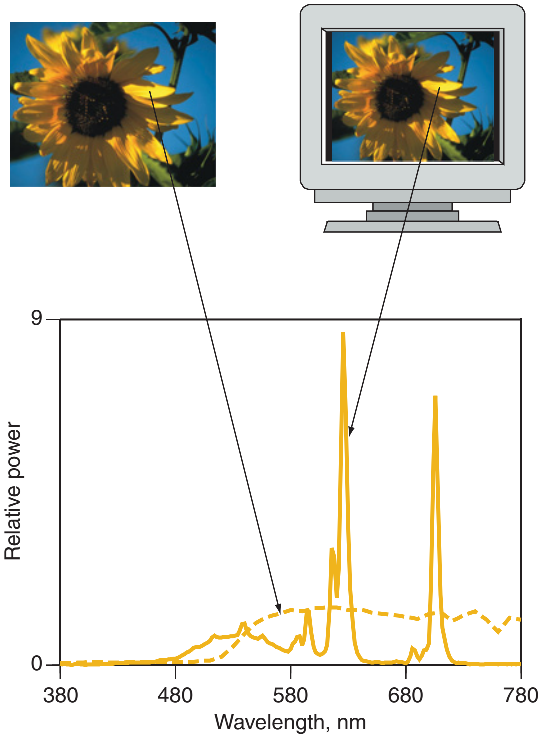


Figure 2.15 Due to the trichromatic nature of human color vision, a computer monitor can replicate the color of a sunflower, although the spectra are dissimilar. *Source:* Berns 2000, p.14.[1] Reproduced with permission of John Wiley & Sons.

identical to the eye. This process is known as *trichromatic vision* and is relevant in a number of imaging applications.

Consider for example, the situation of trying to simulate a sunflower petal on a computer monitor, as shown in Figure 2.15. A computer monitor is unlikely to be able to replicate the real spectrum of the sunflower. However, it does not need to. As we are only seeing the sample spectrum at three regions (cone responses) a spectrum from the display can appear to us to be the same color as a real flower, even though the spectra are quite different.

Another instance where trichromatic vision is applicable, is in viewing booths. Because light booths typically employ fluorescent or LED sources with a spiky spectral power distribution, the spectral power of the light used in a booth is unlikely to be identical to the CIE illuminant it is trying to emulate. The trichromatic nature of human vision, however, allows the booth to “create the impression” of the intended illuminant.

It is possible to measure and verify the light in a viewing booth using a spectrophotometer as shown in Figure 2.16, where the JUST Normlicht LED proofStation 20 light booth is compared to illuminant D50.

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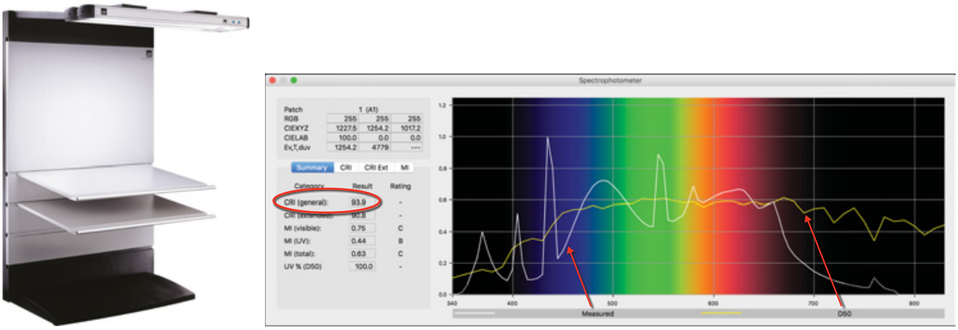
[1] Berns, Roy S., 2000, *Billmeyer and Saltxman’s Principles of Color Technology*, 3rd Ed. New York: Wiley-Interscience.



Patch	1 (A1)		
RGB	255	255	255
CIEXYZ	1227.5	1254.2	1017.2
CIELAB	100.0	0.0	0.0
Ev,T,duv	1254.2	4779	---

Category	Result	Rating
CRI (general):	93.9	-
CRI (extended):	90.8	-
MI (visible):	0.75	C
MI (UV):	0.44	B
MI (total):	0.63	C
UV % (D50)	100.0	-

(a) (b)

Figure 2.16 (a) A JUST Normlicht LED proofStation 20 light booth was measured. (b) Despite the spiky response of the LED source, the booth can accurately create the "effect" of D50, indicated by a high CRI of 93.9. Image (a) reproduced with permission of JUST Normlicht, (b) software shown is basICColor catch 5.

The Color Rendering Index (CRI) is a way of comparing how accurately a light source reproduces the color appearance of a set of samples vs. a CIE standard illuminant. Figure 2.16 shows that the measured light source approximates D50 with a CRI of 93.9. The CRI index is scaled from 0 to 100, with 100 being perfectly equivalent, and >90 is acceptable, so the CRI calculation suggests that these two graphs, despite their very different shape actually represent similar perceived color.

In summary, due to the sampling process within the human trichromatic visual system two objects do not have to have identical spectral power distributions to be a color match. This phenomenon has practical implications as it allows the imaging industry to develop color products at affordable prices.

2.7 Changing the Light Source

We now explore some color viewing phenomena that frequently arise in color-management scenarios – chromatic adaptation and metamerism.

2.7.1 Chromatic Adaptation

The human eye–brain system naturally attempts to adapt to the color change caused by a change in the light source. In a previous section we referred to the color of a sheet of copy paper. If you continue to look at the sheet of paper after a while it would appear "white" under any light (as long as you did not have another object that could be used as a reference). This same process happens in video cameras. Video cameras have a white balance mechanism that allows you to shoot indoors in tungsten lighting or outdoors in daylight without getting a yellow or blue color cast in your images. The camera senses the "color" of the light source and compensates so that the true color of the objects in the scene are recorded. If you have ever made a video recording with the auto white balance turned off you may see a very yellow result on indoor scenes. Some readers may remember photographic film that was not able to "adjust" its white balance and was sold as daylight or tungsten balanced material.

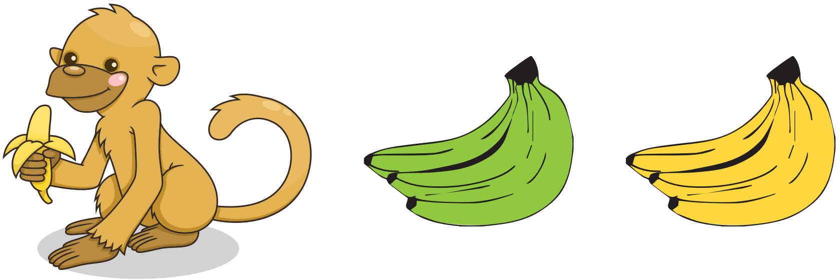


Figure 2.17 Chromatic adaptation evolved as a survival mechanism, from situations in which it was necessary to be able to recognize a raw green banana and a ripe yellow banana in any light condition. © besunnytoo/Shutterstock.

The human visual system also employs a "white balance" mechanism. The human eye compensates for the color and influence of the light source in an attempt to recognize the true color of an object. The process of adapting to the color of the light source is called *chromatic adaptation*.

Chromatic adaptation evolved in humans as a survival mechanism, from situations in which it was necessary to be able to recognize the color of food, friends, and foe in different lighting conditions. If our ancestral monkeys wanted to choose a ripe banana, they may be foraging in the early morning blue light of sunrise or in the long warm rays of the evening during sunset, Figure 2.17. These are two very different lighting conditions, yet they still need to distinguish between a ripe yellow, sweet banana and green, raw banana. This natural chromatic adaptation process enables us to distinguish between a raw green banana and a ripe yellow banana in any light condition.

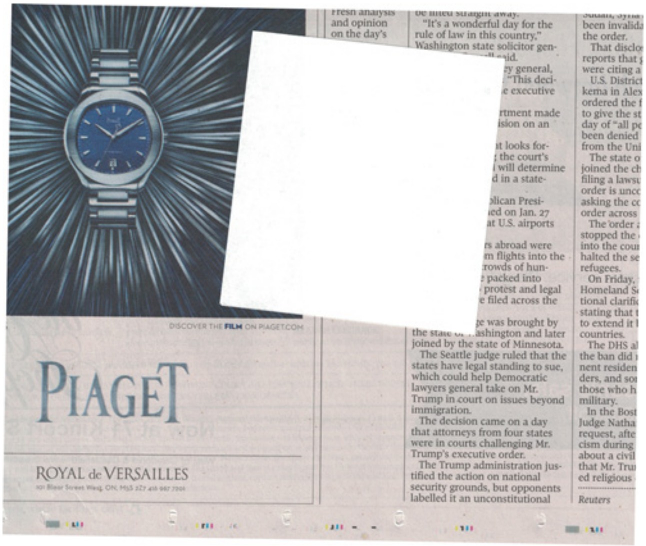
Chromatic adaptation is in play when a plain sheet of paper may initially appear yellow under tungsten light but after a few moments our eyes adjust and we see the paper as "white." Newspapers are printed on very off-white newsprint stock, but the paper does not appear colored when viewed on its own. A newspaper does not appear yellow during normal reading as we have adapted to the yellow white point of the paper and no longer think "this is a very yellow newspaper," but if you were to place a sheet of white copy paper next to the newspaper, you would see the difference, Figure 2.18.

Another example of practical chromatic adaptation occurs when using a home projector in a basement with light pastel colored walls. Yellow or cream walls appear "white" after chromatic adjustment, and no longer appear "colored" while watching an action movie.

Chromatic adaptation is a process in which we adjust to the predominant light in the image and re-calibrate to the new white point. Everything is then viewed relative to this new light source, which becomes "white" irrespective of the actual color of the viewing conditions. We adapt to the highlights in an image and after a few moments, we see the highlight area as white – irrespective of what the color of the sample actually is.

2.7.2 Yellow Sodium-Vapor Street Lighting

Chromatic adaptation can only deal with small variations in the color of a light source. For severe changes in the color of the light source we will see a change in the color of the object.



and opinion
on the day's

"It's a wonderful day for the
rule of law in this country,"
Washington state solicitor gen-
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y general,
"This deci-
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ashington and later
joined by the state of Minnesota.
The Seattle judge ruled that the
states have legal standing to sue,
which could help Democratic
lawyers general take on Mr.
Trump in court on issues beyond
immigration.
The decision came on a day
that attorneys from four states
were in courts challenging Mr.
Trump's executive order.
The Trump administration jus-
tified the action on national
security grounds, but opponents
labelled it an unconstitutional

been invalida
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Figure 2.18 Daily newspapers are printed on very off-white newsprint stock, but due to chromatic adaptation this is not evident when the paper is viewed on its own. The tint of the newspaper is only evident when compared next to bright white copy paper.

To illustrate this point let us look at the effect of a dramatic change in the color of the light source. Consider the example of a car parked in the road under a street lamp, as shown in Figure 2.19. You may have parked your car during the day and returned to it at night and not been able to find it as it has appeared to change color! During the day the car is illuminated by daylight and looks blue, Figure 2.19a. After dark, when the car is only illuminated by a streetlamp, it may look a totally different color, perhaps silver or dark gray, Figure 2.19b.

Let's examine this scenario in terms of the spectra of the car and the light source. The car in this instance is blue so its spectrum shows a high reflectance in the blue wavelengths, as shown in Figure 2.20a. During the day the car is illuminated with daylight,

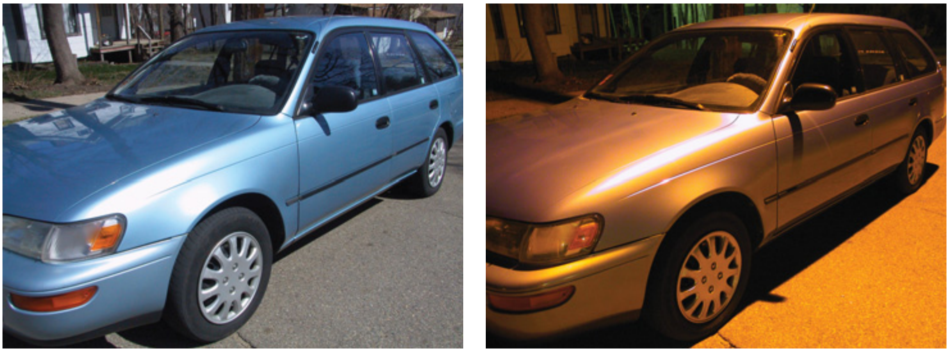

(a)
(b)

Figure 2.19 During the day (a) a car may look blue, while at night (b) it can look silver or gray. These are real pictures, taken in Kalamazoo, Michigan.

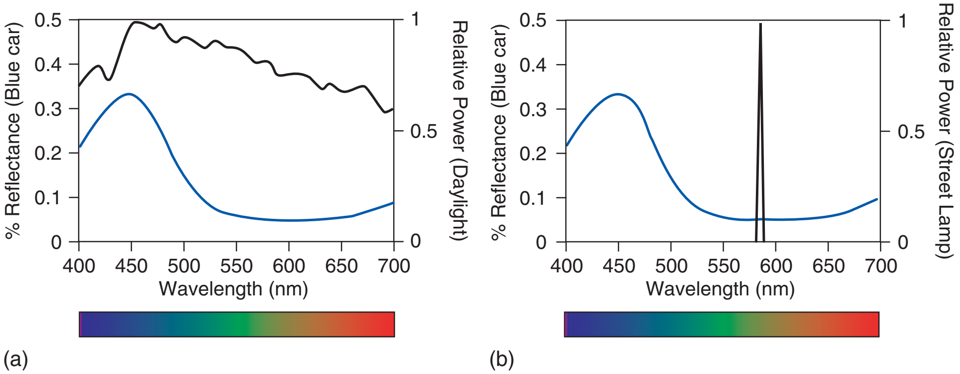


Figure 2.20 An analysis of the spectral curves of the car and the light sources can explain the change in color. (a) Daylight has a broad spectrum which reflects off the car making it appear blue. (b) Night-time street lighting has a narrow yellow spectrum that does not contain blue wavelengths so none are available to be reflected from the car's surface.

which contains a good spread of radiation across the entire spectrum. Radiation between 400 and 500 nm (blue) falls on the car and is reflected, which is why we see the car as blue.

Radiation in the 500–600 nm (green) and 600–700 nm (red) ranges also falls on the car. However, the car does not reflect back much of these wavelengths, and therefore we do not see them, so the illumination in this part of the spectrum is not used. At night-time there is no daylight, and the car is only illuminated with yellow light from a street lamp. Street lamps are often high-pressure sodium-vapor lamps that emit most of their radiation as a very narrow spike in the green–red part of the spectrum, as shown in Figure 2.20b. The blue paint of the car does not have much reflectance in this part of the spectrum, and so very little blue–green–red wavelengths are reflected from the surface of the car. Thus, very little color is returned to the observer, and as a result the car looks devoid of color and neutral – silver or gray. This example demonstrates why it is so important in color management to take into account the color of the light being used to view the object.

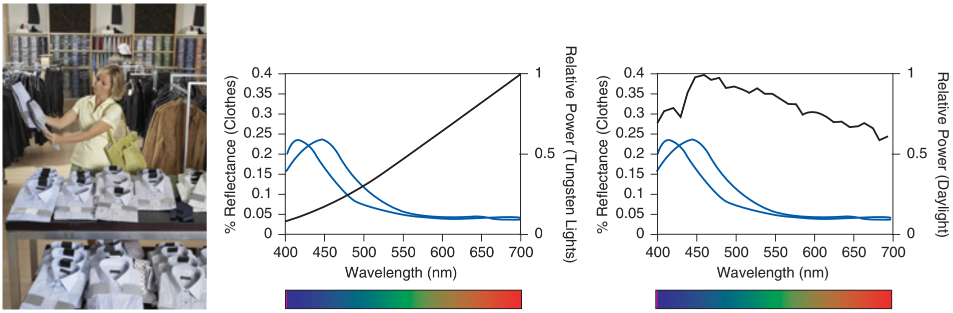
Note that our response at low light levels (scotopic vision) is slightly different from our response at normal light levels (photopic vision) and this can exaggerate the color change described here.

In summary, we see that the color of an object depends not only on its own spectral characteristics but also on the light source providing the illumination.

2.7.3 Metamerism – Matching Jacket and Trousers

Consider a situation, that we refer to as the "jacket–trousers" scenario, as shown in Figure 2.21a. In this scenario, two objects can look the same under one illuminant but different under another light source. The jacket–trousers example refers to the situation in which a customer purchases a jacket and trousers that are a good color match in store lighting, but when worn outside in daylight they do not seem to match very well. This effect is called metamerism, and it has considerable implications for color management.

The jacket and trousers could be made by different manufacturers, but they are sold as a pair and match under store lighting. In this example, we assume the store used



(a) (b) (c)

Figure 2.21 (a) Due to metamerism, a jacket and trousers can appear to match in store lighting but look different in daylight. Spectral analysis shows why metamerism occurs. *Source:* Fotosearch. Reproduced with permission of Publitek, Inc., Dba Fotosearch. (b) Tungsten light has very little emission in the blue part of the spectrum, so although the spectra of the samples is different this is not visible. (c) Daylight has a large blue component which reveals the difference in the color of the garments.

tungsten lighting. The spectra of the jacket and trousers are slightly different (see Figure 2.21b), but the human eye averages the color impression from the samples, and the predominantly red distribution of the tungsten illuminant masks the small difference in the sample spectra. The customer approves the pair of garments in the store and leaves. On wearing the clothes in daylight, however, the customer notes that the jacket and trousers appear to be a different color. This is because under a daylight-type illuminant, the small difference between the jacket and trousers is accentuated. As daylight contains considerable energy in the blue part of the spectrum, this will cause the different spectra to appear different. Thus the jacket and trousers may match under tungsten lighting, but will appear different when viewed in daylight.

When two samples appear to match under one illuminant but are different under another illuminant, this phenomenon is known as *metamerism*, and the samples are known as a *metameric pair*.

The only way to guarantee that two samples are exactly the same color under all illumination conditions is to ensure that they have exactly the same spectrum. In other words, they have to be printed with the same inks on the same paper, or the same dye on the same cloth sample. If the jacket and trousers had been made by the same manufacturer, in the same way, and had identical spectra, no illuminant could make them look different. A tungsten source may cause them to look warmer, but they would both look warmer. In fluorescent lighting they may look colder, but they would both look equally colder.

It is easy to see how metamerism can be a problem in the clothing industry. Different materials often require different colorants. For example, the thread for stitching a garment may be quite separate from the cloth itself. The thread and cloth may appear to match, but under certain viewing conditions the “invisible seam” may become visible.

Metamerism is ever present in the prepress environment. A print shop may generate an excellent match between two samples, perhaps an offset press sheet and an inkjet proof, Figure 2.22. The print shop evaluates all prints in a D50 viewing booth. However, as soon as the customer walks across the car park in daylight or takes the samples back to their office, the samples may cease to match due to metamerism. Both print shop

Figure 2.22 An inkjet proof and a press sheet have different spectral compositions and due to metamerism, may match in one lighting condition but not in another.

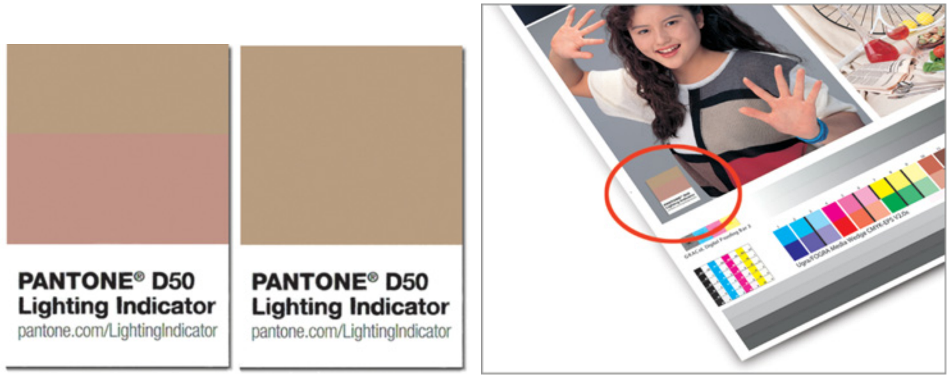
and customer can insist on the truth to their side of the story, the printer claiming the samples matched and the customer complaining that they now do not. In such situations only the agreement of standardized viewing conditions can solve the impasse.

2.7.4 PANTONE® D50 Lighting Indicator

While metamerism is often considered a bit of a nuisance there is a useful application for a metameric pair of materials as a lighting indicator, such as the PANTONE® D50 Lighting Indicator, Figure 2.23. In this small label, the top and bottom materials are different, but are chosen in such a way that they will look alike under D50 illumination. Marketed as a "D50 Lighting Indicator" the top and bottom areas will look alike under D50 and different under non-D50 light sources. The sticker can be placed in the corner of a contract proof used to gain customer approval. The sticker will show whether the user is using a lighting condition that approximates D50. There is a D50 and D65 version of this tool.

2.8 Vision and Measurement

For color imaging to work it is important that imaging technologies mimic the way humans see color. This means that imaging devices such as cameras, and measuring instruments such as spectrophotometers, have a response that is similar to ours. If the sensor in a digital camera has a response similar to our own the image of a scene will correspond to what the scene would look like as if we were viewing it.



(a)

(b)

Figure 2.23 (a) The PANTONE® D50 Lighting Indicator is printed with metameric inks so that the top and bottom halves are different in non-D50 lighting, but match in D50 lighting. (b) The 2 x 0.75″ sticker can be attached to color proofs to indicate if the proof is being viewed in correct lighting. *Source:* X-Rite. Reproduced with permission of X-Rite Incorporated.

Human vision, however, is a complex phenomenon that relies on a number of physical, physiological, and psychological effects that may not always be replicated exactly by devices or instruments. This section describes situations in which the response of the human eye may differ from that of an imaging device or measurement system.

2.8.1 Viewing the Invisible – Infrared

We have seen that the human eye is sensitive to wavelengths in the visible part of the spectrum. Waves outside this region do not trigger any response in our eye–brain system, and these waves are invisible to us. There are occasions when detector systems can record radiation adjacent to the visible band, that is, ultraviolet or infrared radiation. Spectral camera systems can have spectral sensitivity bands outside the visible range and are used in many technical and scientific applications such as aerial geographical studies, museum restoration projects or forensic work.

Let’s look at the example of a camera system that has sensitivity in the infrared part of the spectrum. Infrared imaging systems may have sensitivity to the visible part of the spectrum, and can be specially sensitized to increase their sensitivity into infrared wavelengths. To make the infrared information visible to us the sensor records infrared data that can be encoded as an increased red color. Images with trees and other vegetation are particularly dramatic to record in infrared because chlorophyll strongly reflects in the infrared part of the spectrum, as shown in Figure 2.24.

Normal camera systems produce images that are pleasing to us because the sensitivity of the sensor system has been adjusted to match the sensitivity range of the human eye. An infrared image looks strange to us because the sensor records wavelength bands that are ignored by the human eye. The point we wish to make here is that a sensor system with extended infrared sensitivity does not look natural to us because our sensitivity and the sensor’s sensitivity do not match. It is important to devise imaging systems that mimic human vision, and we need to be careful whenever an imaging system behaves differently from the way humans perceive color.

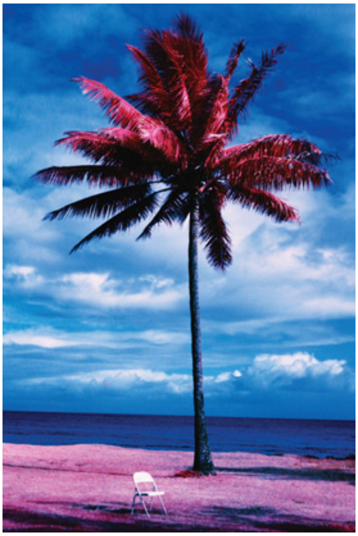


Figure 2.24 Special infrared film "sees" wavelengths we do not, creating unnatural results such as this image with a red palm tree and red grass. ©Thinkstock.

2.8.2 Ultraviolet Fluorescence

Consider another example in which the sensitivities of the imaging system are dissimilar to those of the human eye. Fluorescence is a big issue in color management. Fluorescence is similar to the infrared example, only this time instead of using invisible infrared wavelengths we use invisible ultraviolet wavelengths. Fluorescence is a phenomenon whereby ultraviolet radiation is absorbed by special chemicals in a material and emitted in the visible (blue) part of the spectrum. The blue part of the spectrum is boosted, and we see the material as bluer and brighter. Under light sources with a large ultraviolet content, these items may even appear to glow, such as your T-shirt or white running shoes in a nightclub.

The chemicals that create fluorescence are called optical brightening agents, and many everyday items (such as paint, clothes, detergents, and photographic, inkjet, and offset papers) incorporate these agents. These chemicals ensure your washing to have "whiter whites" and your printing papers will look bluer and brighter.

Whenever there is a difference between what a human observer sees and what a measuring instrument measures – we have a potential problem. This situation occurs when dealing with fluorescence in papers as the amount of UV in the illuminant can be continuously changing (indoor, outdoors, hallway, sunshine), while the measurement system is fixed. Therefore, although it may be beneficial to use wavelengths outside the visible spectrum, we need to ensure that all parts of the imaging system are adjusted accordingly.

2.8.3 Color Illusions

Let us now consider the psychophysical aspects of human color vision.

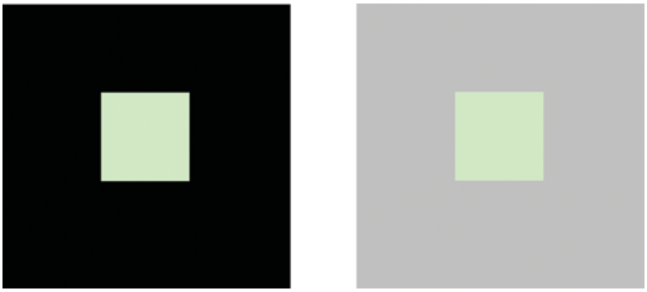


Figure 2.25 The color of the patch in the center appears to change depending on the color of its surroundings. When analyzing colors, we should consider the print border and viewing environment.

The color of a printed patch depends not only on the color of the patch but also on the surrounding colors, an example of which is shown in Figure 2.25. This means that a color patch can appear lighter or darker, or even a different hue, merely by different surround colors. When we look at a printed image the eye may be focused directly on the detail of primary interest, but it is not possible to turn off the input from the rest of the field of view. A spot measuring instrument will see these samples as identical while a human observer may be affected by the surround and see them as different colors. This situation may arise in practice when we use a colored print surround, or view prints in a room with brightly colored walls or the background color of your desktop screen.

In Figure 2.26 the girl on the pony has only one color in her shirt – gray. However, the surrounding image content affects our perception of this color, and we see the girl's shirt as pink or orange. A measuring instrument samples only a small spot and is not fooled by the surroundings. As it stands, the spot measurement device would report a neutral gray color, while human viewing would suggest the shirt was orange.

If we covered up the surrounding image and viewed the girl in isolation, our impression would then agree with the measuring instrument. You can try this yourself – a hole punch makes an appropriate mask. Such differences between measurement and perception create problems in implementing a color-managed system.

Thankfully, most images are not as extreme as those used in these examples. Nevertheless, we must always be aware of what is in the total field of view and its likely impact on the colors under consideration. In all instances a measuring instrument should match, as best as possible, the human perception of colors, and a color management system will be challenged when the two diverge.

2.8.4 Color Appearance Modeling

The issue of physiological and psychological aspects of human vision arise again and again in color management. Consider the situation in which a color is measured on screen and another color is measured from a reflection print. Monitor colors are created by light being emitted from the monitor faceplate. Printed colors are viewed in reflection with light being reflected off the paper surface. Because of this difference in viewing condition we perceive the colors differently, but a measuring instrument is not affected

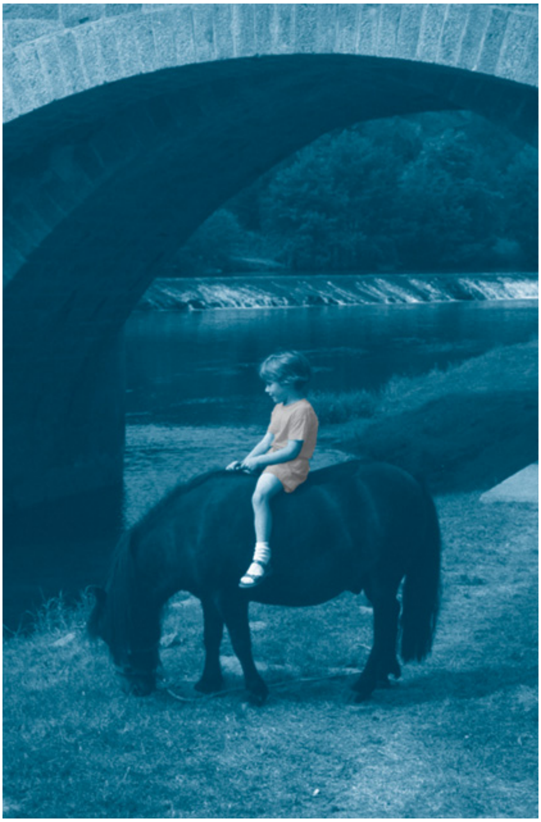


Figure 2.26 The girl on the pony has only one color in her shirt – gray. Make a small hole in a sheet of paper and view only the girl's shirt, and it will look gray! Source: Green, 1999, figure 1.15, p.22.[2] Reproduced with permission of Printing Industries Press.

and could measure the same numeric figure for both samples. How do you take into account psychophysical effects?

There are two ways to approach the problem. One is to use mathematical models to make allowances for these types of conditional viewing phenomena, and the other is to reduce the source of the problem (i.e. reduce differences in the surroundings and standardize on some fixed viewing conditions). The mathematical approach is an area of active research known as *color appearance modeling*, which provides a mechanism for incorporating the effect of the viewing environment. Color appearance modeling is used in an implementation of the Windows Color System (WCS) and is explored further in Chapter 10 XML and Color Management.

In most ICC-based color management, operations are done under controlled conditions, and this reduces any differences in viewing environment by explicitly removing the cause of the problem.

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[2] Green, Phil, 1999, *Understanding Digial Color*, 2nd Ed. Printing Industries Press.

2.9 Summary

For color imaging to work, we need to understand what contributes to how we see color. The three main factors that contribute to the perception of color are the light source, the object, and the human observer. In this chapter we saw that it is possible to define the spectral response of each of these. We saw that you can specify an illuminant in terms of its spectral power distribution or by using a single color temperature number. The CIE has stipulated a number of “standard” illuminants, the most important being daylight illuminants, such as D50.

We saw how to measure the object spectrum. We saw that if the spectrum is measured as a reflectance or transmittance percentage we can draw a spectral curve that represents the object and does not include the effects of the illuminant. Thus the spectrum is a complete descriptor of an object color and allows us to predict what the object will look like under different conditions and we saw that the CIE standard observer is a way to quantify the response of the human visual system – it represents how humans see color.

Color is an impression that we form in our brains. One advantage of human trichromatic vision is that the spectra of two objects does not have to be identical for the objects to be a color match, such as in the examples of the sunflower or a light booth.

In everyday situations we come across puzzling instances of objects that appear to change color, such as the color of a car in daylight and the same car under street lamps, or a jacket and trousers metameric pair. From an analysis of the underlying processes it is easy to see what is going on. Such understanding gives us an insight into how the color of objects may appear to us and helps us to establish proper conditions for viewing and reproducing images.

This chapter has pointed out a number of issues that serve to warn the reader of issues in a color-managed system. Color management will only work if we are aware of, and specify, all parameters that affect our perception of color. “Standardized” metrics and specifications, such as D50 lighting, 2° observer, etc. therefore form the mainstay of daily color management procedures.

3

Color by Numbers

Objectives

- Define the perceptual attributes of color: hue, saturation, and lightness.
- Describe the Munsell Color System.
- Explore XYZ as the basis for all color math.
- Describe CIE color systems, including, Yxy, L*a*b*, and L*C*h.
- Identify L*a*b* as the primary color space for color management.
- Explain the ΔE equation for color differencing.

3.1 Introduction

Color is primarily a subjective phenomenon – that is, it is an impression that we form in our brains. This means that the assessment of color can vary between individuals; the customer may see a large color difference, whereas the print provider may insist that the samples are a close match! Even the same individual can make varying color judgments on different days or at different times of the day – the observer may be fresh in the morning and tired toward the afternoon.

Most human observers have poor memory for color. We are unable to detect differences if the samples are in different rooms or if the operator is asked to compare today's prints with yesterday's prints. For these reasons it is very difficult to manage color with a process based solely on human vision. *Modern color control and color management has moved away from the subjective evaluation of color and is, without exception, based on measuring systems that provide repeatable, numeric values for color.*

The CIE specifies today's color measurement systems. CIE color systems are successful because they "see" the way we see. CIE calculations take into account the "light source–object–human observer", set of factors, and thus take into account all the factors that affect the way humans perceive color. *CIE metrics provide a good correlation with perceived color.*

This chapter describes the main CIE systems used in color management, namely XYZ, Yxy, L*a*b*, and L*C*h.

Color scientists continue to develop new color systems and variations with the goal of providing better perceptual uniformity. In this chapter we see that Yxy has some serious

Understanding Color Management, Second Edition. Abhay Sharma.
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flaws. An improved system, approved by the CIE in 1976, is known officially as CIE 1976 L*, a*, b*, pronounced “see-lab”. For clarity and brevity in this text, we use a shorter, unofficial syntax – L*a*b*.

In day to day color management it is very useful to be able to specify the difference between two colors by a single numeric value. A measure of color difference is called Delta E (ΔE). CIE systems are being continuously improved by active color science research, therefore, different versions of ΔE are examined.

The overriding message of this chapter is that CIE-based color systems are well-accepted, visually-relevant, standardized, instrument-based, numerical methods, for color specification and today, form the basis for managing and monitoring all aspects of color management.

3.2 Basic Attributes of Color: Hue, Saturation, and Lightness

In this chapter we explore a number of different color specification systems. The color systems we describe have one thing in common. They all depict three basic attributes of color: hue, saturation, and lightness. Figure 3.1 shows how these may be represented. The vertical axis corresponds to *lightness*. In this arrangement, dark colors (black) are at the base, and light colors (white) are near the top, with a range of grays in-between. Other colors also change in lightness as we move from top to bottom.

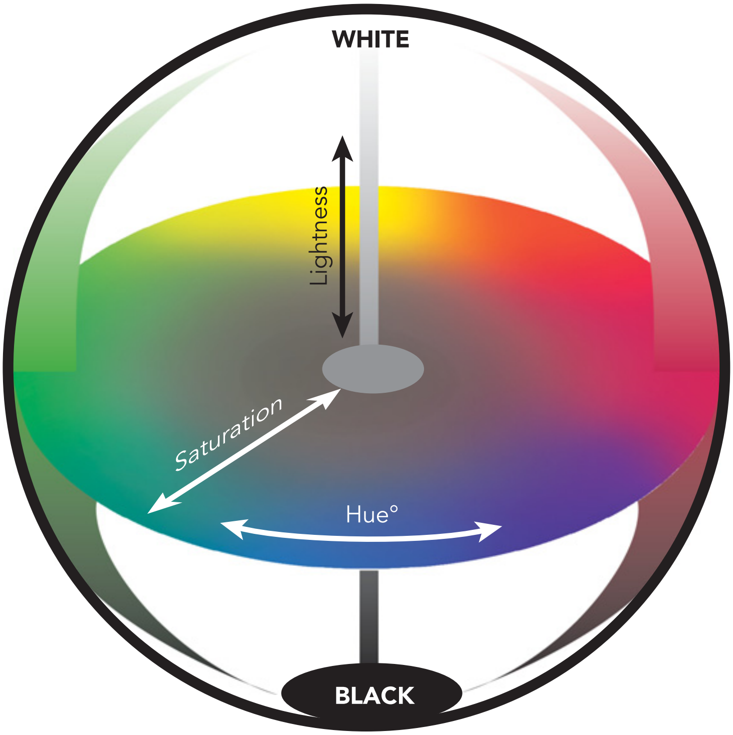


Figure 3.1 Color has three basic perceptual attributes: hue, saturation, and lightness. The color systems described in this chapter all incorporate these three attributes. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

Near the center of the sphere, colors are desaturated or neutral. The color of a sample can change in *saturation*, which in Figure 3.1 is visualized as moving from the center of the sphere outward. Moving outward toward the edge, the color becomes more saturated, or pure. Note that the "color" does not change. That is, a green stays a green; it simply becomes more saturated or vivid. Saturation is also referred to as a color's chroma.

The final attribute is *hue*. It is possible to change the main or "starting" shade of a color by moving around the circumference of the sphere. This alters the hue or dominant wavelength of a color. As you can see from Figure 3.1, the colors change as you move around the "hue circle" from blue to red to yellow to green.

An important point relating to color assessment is that the human eye is least sensitive to changes in lightness, more sensitive to changes in saturation, and most sensitive to a change in hue. Consider two colored samples. These samples can be different in lightness without this being immediately obvious to the naked eye. However, the eye will be fairly quick to notice the same degree of difference in regard to saturation. The same degree of difference in regard to hue is even more obvious visually.

A *color system* is a systematic way of arranging colors, and as color has three attributes (lightness, saturation and hue), we would normally need a three-dimensional system. In this chapter we describe the following color systems – the Munsell Color System, Yxy, and L*a*b*. All these color systems incorporate the three basic attributes of color. The Munsell system is based on color chips and is therefore discrete, that is, it only covers specific colors and not the colors in between. The L*a*b* and Yxy systems are numerical systems and therefore provide continuous dimensions for the chosen attributes, making it possible to specify any color.

Later in this text we will consider different device colorspaces. A *colorspace* is data for a real device, expressed in one of the three-dimensional color systems. Thus we may have a digital camera's colorspace or the sRGB colorspace, etc. A colorspace uses the axis and coordinates for a particular color system but with real, measured, device values. (In this text we do not always adhere to this strict definition, and the terms color system and colorspace may be used interchangeably.)

3.3 Munsell Color System

Historically, natural scientists and artists have been interested in creating some systematic, ordered arrangement of colors. The Munsell Color System, developed by Albert Munsell in 1905 as a teaching aid for his art students, began the process for the "quantification" of color. The Munsell Color System treats color in accordance with the basic attributes of color, i.e. hue, saturation and lightness.

A physical model of the Munsell Color System is called the Munsell color tree, Figure 3.2a. Munsell's aim was to have a system of specifying color that was both visual and numerical. *A fundamental principle of his system was equal spacing of colors.* Considerable trouble was taken in arranging the patches so that the difference between any two adjacent patches is always visually the same. Thus two side-by-side patches in the red region create the same visual color difference as two side-by-side patches in the green region. Furthermore, adjacent horizontal and vertical chips create a similar visual color difference.

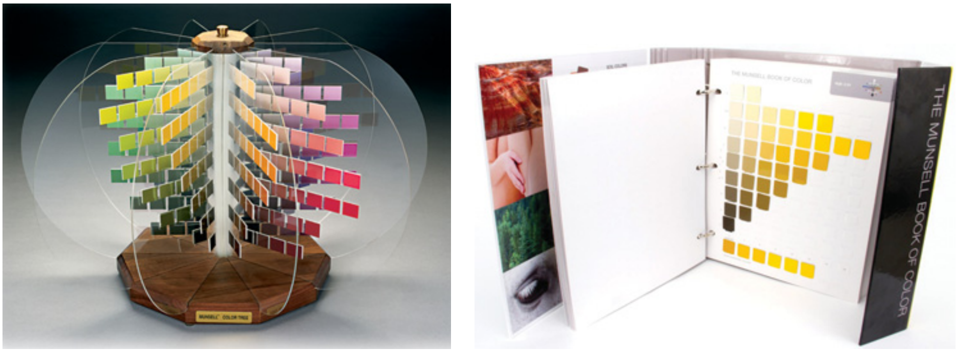

(a) (b)

Figure 3.2 (a) A physical model of the Munsell Color System is called the Munsell color tree. (b) A modern version is the $1000 Munsell Book of Color. *Source:* X-Rite. Reproduced with permission of X-Rite Incorporated.

In 1915 the system was published as the Atlas of the Munsell Color System, and today it is available as a printed swatch book, called the Munsell Book of Color, Figure 3.2b.

The Munsell Color System uses dimensions of hue, saturation and lightness, referred to as Munsell hue, Munsell chroma, and Munsell value, respectively. For practical reasons, the extent of the chroma is different for different hues so the Munsell "volume" does not constitute a perfectly circular sphere.

One of the reasons to mention the Munsell system is the close similarity it has with the modern-day L*a*b* color space, to be defined shortly. In fact, the L^* lightness axis correlates more or less exactly with Munsell value. Both the Munsell system and L*a*b*, provide a numerical specification of color, and both aim to be perceptually uniform. The main difference between the Munsell and the L*a*b* systems is that the former uses color patches at discrete steps, so there are jumps between colors, whereas L*a*b* uses numbers only, and is a continuous space that can locate and numerically specify any color in a three-dimensional volume.

3.4 CIE Color Specification

The Commission Internationale de l'Eclairage (CIE) or in English – International Commission on Illumination, defines a number of color systems. The CIE systems provide a *descriptor* or *specification* of a color, independent of how the color was formed.

Let us see how CIE metrics are calculated and how they relate to each other. The components that we are going to consider are shown in Figure 3.3. We know that there are three factors that affect the way humans perceive color. Three spectral graphs (on the left in Figure 3.3) show how we incorporate information relating to the light source–sample–human observer triad of factors. The light source is specified by using data for the spectral energy distribution of the light source, and is often a CIE illuminant. The transmission or reflection spectrum describes the sample, and the color-matching functions for the CIE standard observer represent the response of the human visual system. *CIE metrics take into account all factors that affect the way we see color, this means that CIE metrics correlate well with the human perception of color* – this is one of the reasons

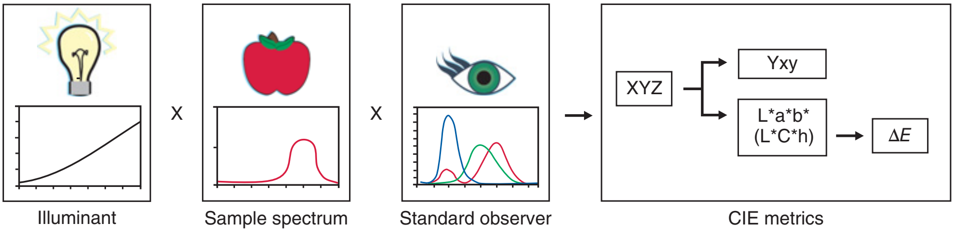


Figure 3.3 Data for the illuminant, the sample, and the human observer are used to derive XYZ and all other CIE metrics.

for their usefulness and wide acceptance in color management. It is relevant to note that an older metric, density, is less useful in color measurement, as it does not consider the factors just described.

In the CIE system, the starting point for all color specifications is XYZ. XYZ are known as *tristimulus values*, and it is customary to show them in capital letters to distinguish them from other similar notations. XYZ tristimulus values are three numbers that specify a color. We arrive at XYZ values by multiplying together the three spectral graphs representing the light source, the sample, and the human observer. A spreadsheet for this calculation is provided in Table 3.1.

XYZ may be used directly in a number of color management operations, for example, in ICC monitor profiles. However, for user-level implementation, XYZ values are usually transformed into Yxy, L*a*b*, or L*C*h. And equations for ΔE color differencing may be computed.

Notice that from Figure 3.3, XYZ has given rise to two different color spaces – Yxy and L*a*b*. Both are in general use today. The attempt from 1931 was a good approximation for a numerical way of describing color, but has serious flaws in terms of perceptual nonuniformity. The L*a*b* system, approved in 1976, is much more perceptually uniform, as described below.

3.5 XYZ Tristimulus Values

In the CIE system, the starting point for all color calculations is XYZ. To determine the color of a sample, you first need to compute XYZ, and then use equations to derive other metrics.

3.5.1 Calculating XYZ

The computation of XYZ is usually done within a measuring instrument. An instrument can measure a sample spectrum and internally multiply the values represented by the illuminant and the color-matching function graphs to compute XYZ.

Manually performing the calculation, however, helps us to understand the fundamental principles involved. For those interested in the details, the mathematical process for the computation of XYZ is now described, using Table 3.1.

To manually calculate XYZ you need data for the previously mentioned three spectral graphs representing the illuminant shining on the object; the object reflectance, and

Table 3.1 Spreadsheet that describes the calculation to convert spectral data to XYZ.

Wavelength (nm)	Illuminant data	Sample Reflectance	Color Matching Functions for the 2° Observer			Normalizing Constant	Tristimulus Products		
λ	D65	%R	$\bar{x}$	$\bar{y}$	$\bar{z}$	D65 $\times \bar{y}$	D65 $\times$ %$R \times \bar{x}$	D65 $\times$ %$R \times \bar{y}$	D65 $\times$ %$R \times \bar{z}$
380	49.980	8.240	0.001	0.000	0.007	0.000	0.577	0.000	2.677
390	54.650	8.870	0.004	0.000	0.020	0.005	2.036	0.048	9.743
400	82.750	9.460	0.014	0.000	0.068	0.033	11.194	0.313	53.153
410	91.490	9.820	0.044	0.001	0.207	0.110	39.082	1.078	186.335
420	93.430	10.120	0.134	0.004	0.646	0.374	127.077	3.782	610.422
430	86.680	10.420	0.284	0.012	1.386	1.005	256.420	10.477	1251.482
440	104.860	10.780	0.348	0.023	1.747	2.412	393.715	25.999	1974.906
–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–
720	61.600	13.440	0.003	0.001	0.000	0.062	2.401	0.828	0.000
730	69.890	13.540	0.001	0.001	0.000	0.035	1.325	0.473	0.000
740	75.087	0.000	0.001	0.000	0.000	0.023	0.000	0.000	0.000
750	63.593	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
760	46.418	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000
770	66.805	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
					Sum	1056.776	15029.061	25921.065	15530.398
							$X = \frac{15029.061}{1056.776}$	$Y = \frac{25921.065}{1056.776}$	$Z = \frac{15530.398}{1056.776}$
							$\mathbf{X = 14.222}$	$\mathbf{Y = 24.528}$	$\mathbf{Z = 14.696}$

the color-matching function for the chosen standard observer. What illuminant are you going to use in the calculation? Normally this would be the illuminant you are going to view the sample with. If you are using a standard source it is possible to use illuminant data, such as Illuminant A, D50, or D65. This data is tabulated and is available for download from many web sites. Next, you need the spectrum of the sample. You need to measure the sample with a spectrophotometer which measures spectral reflectance (or transmission) at regular wavelength intervals. You typically need data in the range from 380–780 nm, at 5 or 10 nm intervals. Finally, you need data for the $\bar{x}$, $\bar{y}$, and $\bar{z}$ color-matching functions of the chosen standard observer. In printing and imaging we have seen that it is customary to use data for the 2° observer, though you may have reasons to do the calculation for the 10° observer.

Table 3.1 is a spreadsheet for calculating X, Y, and Z. To calculate XYZ the spectral graphs are multiplied by each other wavelength by wavelength. Thus to calculate X, you multiply the illuminant value by the sample reflectance by the $\bar{x}$ value at each wavelength. You then sum all of these results to derive X. The process is repeated for Y and Z, but instead of using $\bar{x}$, you use $\bar{y}$ and $\bar{z}$, respectively.

By convention, the XYZ values are normalized so we divide by a normalizing constant, which is the sum of D65$\times \bar{y}$. In the example the normalizing constant = 1056.776. The final computation is $X = 14.222$, $Y = 24.528$ and $Z = 14.696$ for a green sample.

You need to pay attention to how your data is arranged. By definition the color-matching functions are defined at 1 nm intervals, but most commercial instruments report spectral measurements at 10 nm or 20 nm increments. Care should be taken when interpolating and extrapolating missing values.

The XYZ calculation depends on what is chosen as the illuminant and which standard observer is used. This means, for example, that you might specify the result with the comment "D50, 2°".

The XYZ values you have just calculated can be compared to a commercial instrument's read out for verification. This spreadsheet calculation is an informative exercise and a valuable color science class project that can show very close correlation between spreadsheet calculated and instrument measured values.

3.5.2 XYZ Example Colors

As an example, three color patches and their XYZ values are shown in Table 3.2. It can be seen that X, Y, and Z correspond (roughly) with red, green, and blue, respectively. Thus, the red color has a high X number, green has a high Y, and blue has a high Z number.

Table 3.2 Three color samples and their corresponding XYZ values. Red corresponds to the strongest X, green corresponds to Y, and blue corresponds to Z.

Sample	X	Y	Z
🟥	35.90	20.25	2.90
🟩	8.36	15.03	3.41
🟦	6.95	5.49	23.09

Table 3.3 It is customary for CIE illuminants to be shown with $Y = 100$. Notice the value of D50, this is close to the value used in an ICC profile header.

Illuminant	***X***	***Y***	***Z***
A	109.850	100.000	35.585
B	99.072	100.000	85.223
C	98.074	100.000	118.232
D50	96.422	100.000	82.521
D65	95.047	100.000	108.883
F2	99.190	100.000	67.390

3.5.3 XYZ for Light Sources

Light sources have a color, and we can therefore compute the XYZ value for a light source. By convention, when computing XYZ, the values are normalized. The effect of the normalization process is that we assign the value of $Y = 100$ to the reference light source, Table 3.3. To understand this concept consider a perfectly reflecting or a perfectly transmitting sample. If light from a source falls on a perfectly reflecting sample, we get all of the light reflected back. Thus when we do the calculation for XYZ the normalization process ensures that the light source, or "white point", has $Y = 100$. There is no similar restriction on the values of X and Z.

D50 has tristimulus values of $X = 96.422$, $Y = 100.000$, and $Z = 82.521$, and some other light sources are shown in Table 3.3. XYZ values are used in practical color management. D50 is the reference illuminant for the ICC profile connection space, as seen in an ICC profile header, Figure 3.4. (The ICC allows XYZ values to use a scale of 0–1 or 0–100, in this profile, the scaling is 0–1.)

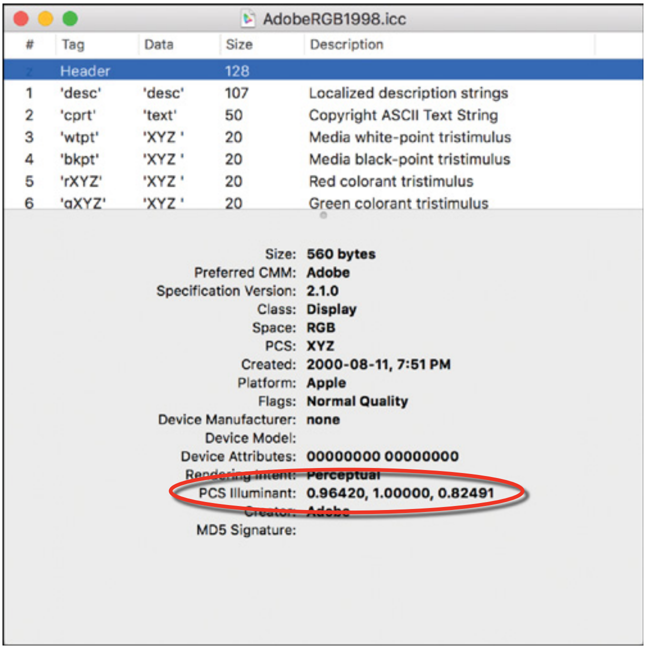
3.6 CIE 1931 Yxy System

XYZ tristimulus values are computed from spectral measurements and provide a fundamental measure of color. However, XYZ values do not give an immediately obvious representation of color. XYZ values can be transformed into other representations as described in this and the following sections. The first system we look at is the CIE 1931 Yxy system. In this system, a color is represented by its x, y coordinates and plotted on a horseshoe-shaped diagram, Figure 3.5a. Green occupies the upper part of the figure, with blue and red in the lower region. An example may be, x, y of 0.2, 0.7 for a green, or x, y of 0.6, 0.3 for a red. This diagram is called the xy chromaticity diagram, and lowercase x, y are known as chromaticity coordinates.

x, y are calculated from the XYZ values of a sample. From XYZ values, we can calculate x and y chromaticity coordinates using the following simple equations:

$$x = \frac{X}{X + Y + Z} \qquad y = \frac{Y}{X + Y + Z}$$

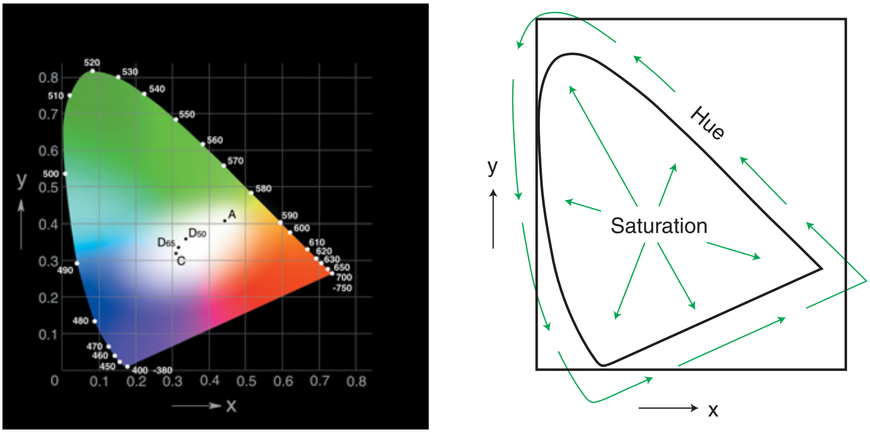
Here, x and y are the chromaticity coordinates, and X, Y, Z are tristimulus values. By convention, lowercase x, y is reserved for the chromaticity coordinates, and uppercase


AdobeRGB1998.icc

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'desc'	107	Localized description strings
2	'cprt'	'text'	50	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'rXYZ'	'XYZ '	20	Red colorant tristimulus
6	'gXYZ'	'XYZ '	20	Green colorant tristimulus

Size: 560 bytes
Preferred CMM: Adobe
Specification Version: 2.1.0
Class: Display
Space: RGB
PCS: XYZ
Created: 2000-08-11, 7:51 PM
Platform: Apple
Flags: Normal Quality
Device Manufacturer: none
Device Model:
Device Attributes: 00000000 00000000
Rendering Intent: Perceptual
PCS Illuminant: 0.96420, 1.00000, 0.82491
Creator: Adobe
MD5 Signature:

Figure 3.4 In an ICC profile, the reference illuminant is specified in terms of the XYZ values for D50.



(a) (b)

Figure 3.5 (a) The 1931 Yxy diagram is horseshoe shaped. (b) Saturation changes from the centre outwards, and hue changes as we go around the diagram. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

(capital) X, Y, Z for the predecessor tristimulus values. The x, y values can be plotted on this diagram to show the position of a color in this color space.

The Yxy system can be explained in terms of the three attributes of color, Figure 3.5b. The hue changes as we go around the outside of the locus. Around the edge of the chromaticity diagram are fully saturated colors, and the locus is labeled with the dominant wavelength. The saturation of a color is depicted by considering the distance of the sample from the locus edge. Thus, neutral samples occupy the center of the diagram, while saturated samples are found nearer the edge of the figure. The Yxy system does not show the attribute of lightness, and the lightness value must be quoted as a separate value (Y).

The chromaticity diagram is widely used in color management, and many programs display colors using this type of plot. Projectors, video and flat-panel markets favor the use of the chromaticity diagram. We now look at the advantages and disadvantages of using the xy chromaticity diagram.

3.6.1 Advantages of the Yxy Chromaticity Diagram

The Yxy chromaticity diagram can be used for a number of calculations and visualizations.

To use this diagram, you first need to calculate or measure the x, y chromaticity coordinates of your sample. You then plot the x, y position of the color and of the illuminant the color was measured under, as shown in Figure 3.6.

(A) Next, a line is drawn, starting from the illuminant (white point), through the color to the locus edge. Here it is possible to read off the dominant wavelength of the sample. It is possible to calculate the saturation of a color by considering the distances of the illuminant to the sample (a) and the distance of the sample to the locus (b). The saturation or purity of a color is given by $a/(a + b)$, and can be expressed as a percentage.

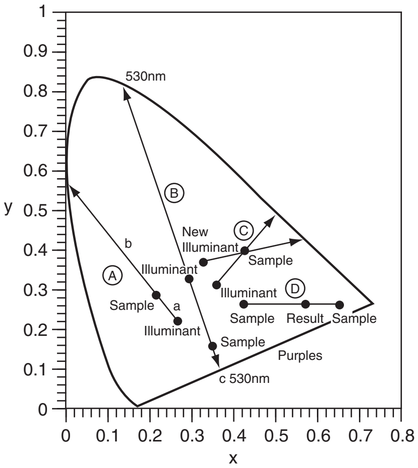


Figure 3.6 The Yxy diagram can be used for a number of color calculations as described in the text.

(B) A straight line is drawn at the base of the horseshoe to connect the ends of the spectrum locus. This is called the purple boundary line. If a line from the illuminant through the sample falls on this boundary, the line is reversed, and a complementary dominant wavelength is quoted (e.g. c530 nm).

(C) It is possible to change the illuminant and predict the effect this has on the appearance of a sample. When we select the coordinates of a new illuminant a line is drawn, starting from the new illuminant, through the sample to the locus edge. Here it is possible to read off a new dominant wavelength, which represents the color of the sample under the new illuminant.

(D) It is possible to add two colors and predict the color of the result. If two emissive colors are represented by two points on the diagram, the result of their addition will always be on the line joining the samples. This concept is often used in display and projector analysis, where the gamut of an additive RGB system is bounded by the line joining the red-green-blue primaries, Figure 3.7. RGB color spaces are often analyzed this way, as it is adequate to know only the red, green and blue coordinates for a system from which the gamut boundary can be drawn. All colors that can be created by these primaries lie within the bounding triangle.

3.6.2 Disadvantages of the Yxy Chromaticity Diagram

The Yxy chromaticity diagram is (unfortunately) widely used in color management. A significant problem with this diagram is that it is *perceptually non-uniform*. Colors with an equal perceptual difference should be equally spaced in the diagram. How far do you have to move in this diagram before two colors look different? If you examine the top part of the diagram, you will see that two colors can be very far apart in the green part of the diagram before they change color, Figure 3.8. In the red and especially

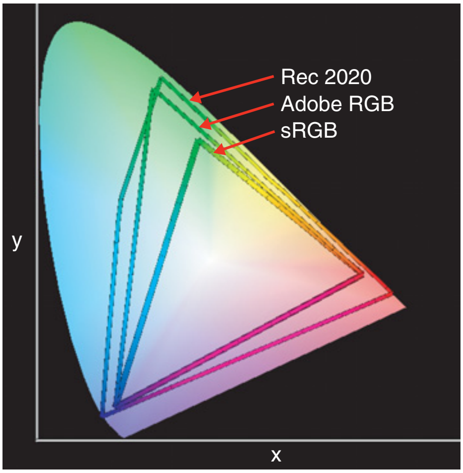
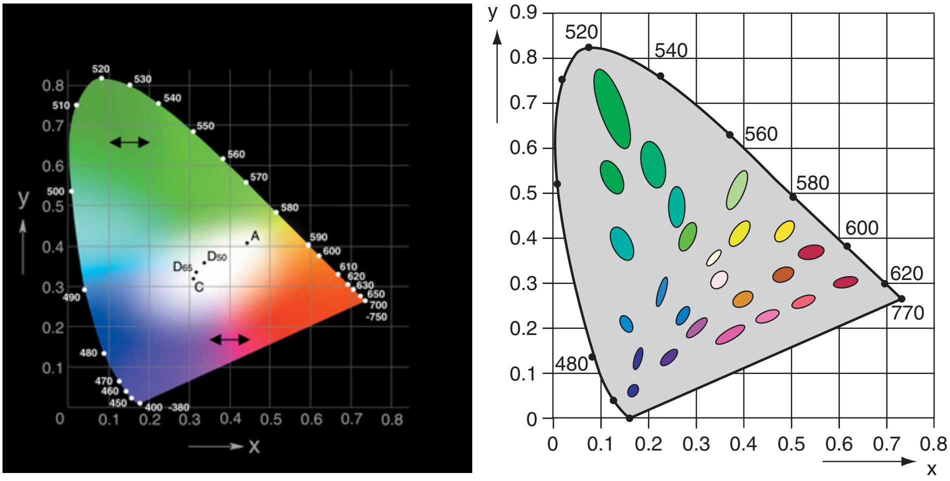


Figure 3.7 The gamut of RGB devices is obtained by a triangle that connects the red, green, blue chromaticities in the Yxy diagram.



(a)

(b)

Figure 3.8 (a) The Yxy diagram is not perceptually uniform, so 1 division is insignificant in the greens, but in another region of the diagram, the same distance can represent a huge change in color from blue to red. (b) MacAdam ellipses indicate areas of just-noticeable color difference, and in a perceptual color space would theoretically all be the same size.

blue part of the figure, the same perceptual difference occurs over a much smaller distance.

If we were to use this diagram to describe a color difference, we would have a problem. Suppose we described a “1 cm” color difference between two samples. In the green this would mean the colors are quite similar, whereas in red this would mean the colors are dramatically different. If this diagram were to be used in conveying color difference information we would always have to provide a clarification. That is, is the “1 cm” color difference in the greens or in the reds? If it is in the greens it is nothing to worry about, however, if that same difference is in the reds, it is very significant. In an ideal color space a “1 cm distance” in the diagram would represent the same perceptual color difference for all colors. This concept is referred to as *perceptual uniformity*. The behavior of the Yxy color space in terms of perception is shown by ellipses called the MacAdam ellipses, Figure 3.8b. Each ellipse represents a just-noticeable color difference. If the color space was perceptually uniform the ellipses would be the same size, throughout the color space.

Another way to illustrate the perceptual non-uniformity of the Yxy diagram is to look at the spacing of the wavelength tick marks around the locus of the diagram, Figure 3.8a or 3.8b. Notice that a 10 nm difference from 490–500 nm is a huge distance, while 620–630 nm is much smaller. Imagine trying to use a ruler that continuously changes its scale!

Another problem with the Yxy color system is the absence of the lightness axis. The Yxy system does not incorporate the Y-axis. The Yxy color space is a two-dimensional color space and Y must be described separately, for example by using a slider in Chromix ColorThink Pro software, Figure 3.9.

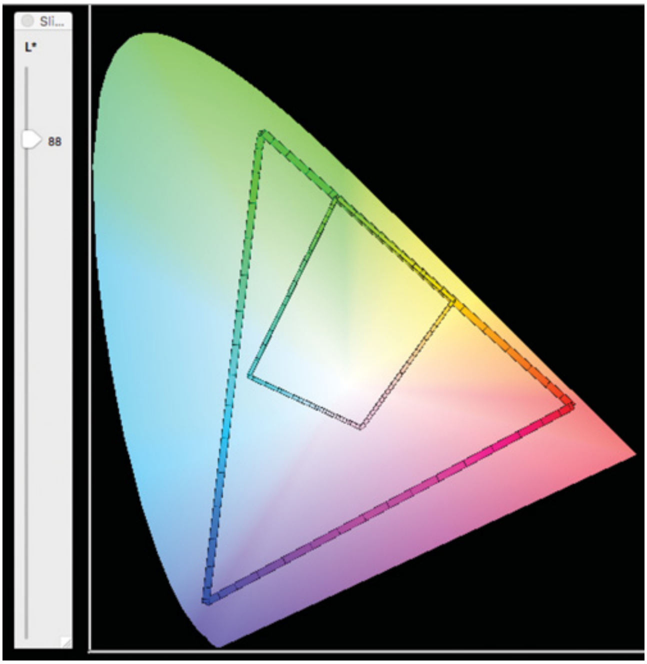


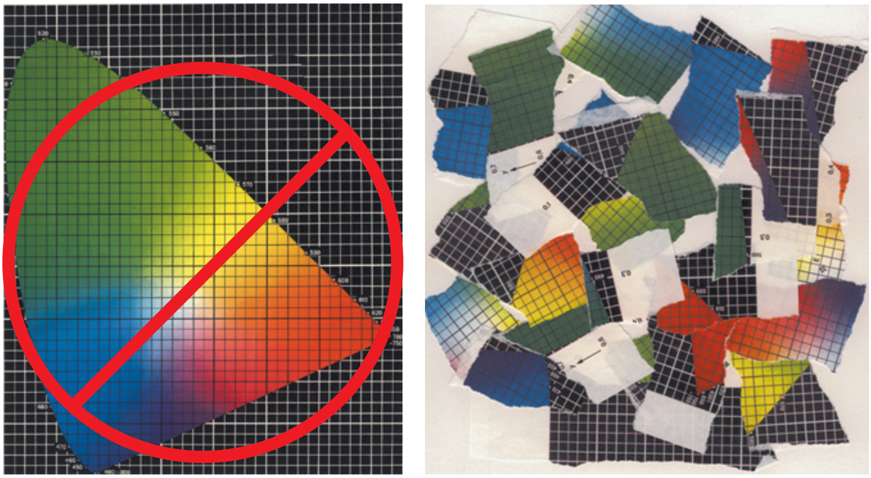
Figure 3.9 The two-dimensional Yxy diagram has no way of showing the *Y* scale, so Chromix ColorThink Pro software provides a slider for this purpose.

There are only a few color operations that are valid to conduct using the Yxy diagram. We have seen that if the RGB emissive colorants are represented by points on the diagram it is possible to predict the color gamut of the device by the lines joining the three colorants. Another valid use of the Yxy diagram is to get an approximation for a color. To estimate a color, we may determine, for example, that x, y of 0.2, 0.7, is a green. Finally, we may use the Yxy diagram to see if two colors are the same. Two colors are the same if they have the same Yxy values. Beyond these very limited applications it is not appropriate to use the Yxy diagram. Most applications where we see the Yxy diagram being used, where the color space is used to compare values or compare device gamuts can be misleading and should be avoided. *Principles of Color Technology* by Roy Berns is a respected text on color science that advises the reader not to use the Yxy diagram and tear up any printed copies, Figure 3.10.

In order to address the perceptual non-uniformity of the Yxy system, the CIE introduced other systems, such as the CIE 1976 u′ v′ (pronounced “u-prime, v-prime”) chromaticity diagram as an attempt to offer better perceptual uniformity. The CIE 1976 u′ v′ chromaticity diagram is commonly used in video and motion-picture applications.

3.7 CIE 1976 L*a*b* System

Historically different versions of Lab exist, such as Hunter Lab and Adams-Nickerson Lab. In order to distinguish from these other versions of Lab, the official CIE version



(a) (b)

Figure 3.10 (a) A distinguished color scientist – Roy Berns, suggests we should not use the Yxy diagram, and (b) suggests tearing up any printed copies! Source: Berns 2000, p.61.[1] Reproduced with permission of John Wiley & Sons.

uses an asterisk – L*a*b* – which is pronounced “l-star, a-star, b-star”. In general, when a unit has been approved and adopted by the CIE, the asterisk symbol is used, thus L*a*b* refers to the CIE-approved Lab system. L*a*b* is widely used throughout color management and in applications such as Adobe Photoshop’s Color Picker dialog, Figure 3.11, though Photoshop’s dialog omits the asterisk.

The L*a*b* color space is represented as a three-dimensional color diagram, as shown in Figure 3.12a, and a slice through this sphere Figure 3.12b, is an often used, two-dimensional representation. The color of a sample is specified by its position in this three-dimensional space, expressed as three numbers that represent L*a*b* coordinates. The L*a*b* system separates the color information into lightness (L^*) and color information on a red/green (a^*) and yellow/blue (b^*) axis. The lightness of a color changes as we move vertically through this solid, with L^* of 0 representing black and L^* of 100 representing white. A typical measurement of a white paper sample may have $L^* = 95$. The a^* and b^* scales go from -128 to $+127$. We describe a perfectly mid-tone gray color by $L^* = 50, a^* = 0, b, = 0$. As the position of a color moves from the central region toward the edge of the sphere, its saturation (or chroma) increases. As we go around the sphere, the hue angle (or dominant wavelength) changes. Thus we see that the three main attributes of color are clearly represented in the L*a*b* system.

*An important difference between the Yxy color space and the L*a*b* color space, is that the L*a*b* system has better perceptual uniformity.* This means that the geometrical distance between colors is more representative of the perceptual difference. Notice, for example, how the green region is much smaller in the L*a*b* diagram compared to the same region in the Yxy chromaticity diagram. Notice also how the L*a*b* is much more

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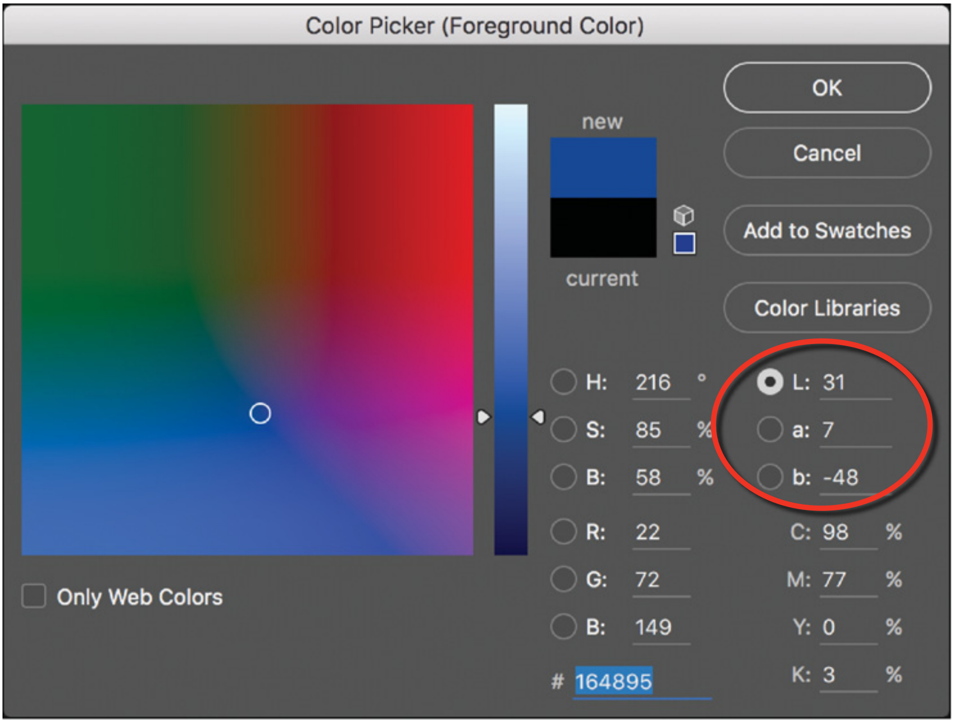
[1] Berns, Roy S., 2000, *Billmeyer and Saltzman’s Principles of Color Technology*, 3rd Ed. New York: Wiley-Interscience.



Color Picker (Foreground Color)

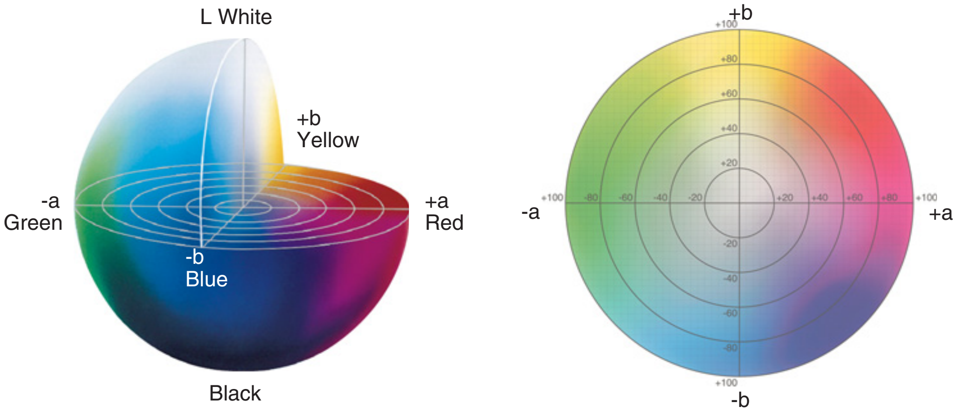
OK
Cancel
new
current
Add to Swatches
Color Libraries

○ H: 216 °
○ S: 85 %
○ B: 58 %
○ R: 22
○ G: 72
○ B: 149
164895

● L: 31
○ a: 7
○ b: -48
C: 98 %
M: 77 %
Y: 0 %
K: 3 %

☐ Only Web Colors

Figure 3.11 L*a*b* is at the heart of Adobe Photoshop's color management system as shown here in the Color Picker dialog.



L White
+b
Yellow
-a
Green
+a
Red
-b
Blue
Black
+b
+100
+80
+60
+40
+20
-a
+100
-80
-60
-40
-20
+20
+40
+60
+80
+100
+a
-20
-40
-60
-80
+100
-b

(a) (b)

Figure 3.12 The L*a*b* system specifies a color by its position in a perceptually uniform (a) three-dimensional color space, or (b) two-dimensional plane. *Source:* Agfa Graphics. Reproduced with permission of Agfa Graphics.

circular compared to the elongated horseshoe shape of the Yxy diagram. Finally note that in the L*a*b* diagram all colors have much more equal spacing and the green area is not overly emphasized. The L*a*b* color space is not perfectly perceptually uniform, but it is much better than Yxy.

L*a*b* is derived from XYZ as follows:

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{1/3} - 16$$

$$a^* = 500\left[\left(\frac{X}{X_n}\right)^{1/3} - \left(\frac{Y}{Y_n}\right)^{1/3}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_n}\right)^{1/3} - \left(\frac{Z}{Z_n}\right)^{1/3}\right]$$

Here, X, Y, Z are the tristimulus values of the sample and X_n, Y_n, and Z_n are the tristimulus values of the reference illuminant (light source). There is a further correction to this equation for very dark colors.

Although it is not necessary to understand these equations in detail, there are a few points that can be made from a cursory glance. We see that both Yxy and L*a*b* are derived from XYZ. However, note how much more complicated the L*a*b* equation is compared to the Yxy equation. The additional computation helps make the L*a*b* system more perceptually uniform. In particular, note how the L*a*b* equation involves functions raised to the power of 1/3 (a cube root function). The cube root function is a nonlinear function, which means that it compresses some values more than others – exactly the sort of correction we want to see happen to the green colors in the color space. *This set of equations, and the constants that have been chosen (116, 500, 200), are responsible for the better (more perceptual) spacing of colors in the L*a*b* diagram.*

The other aspect of the XYZ to L*a*b* conversion worth noting is that the equation considers the viewing illuminant, shown in the equation as X_n, Y_n, and Z_n. The interpretation of this is that L*a*b* expresses the color of a sample as viewed under a particular illuminant, so that if we wanted to predict the color of a sample under a different illuminant we could change the values of X_n, Y_n, and Z_n in the equation.

Color management relies on L*a*b* for a number of significant operations. In fact, it is used to specify the central interchange space – the profile connection space – through which all image data passes in an ICC workflow. *The L*a*b* system is the best and most widely used color space in color management today.*

3.7.1 L*a*b* Practical Examples

It is useful in practical color management to be able to “eyeball” L*a*b* values to visualize their position on the L*a*b* diagram and their relative position to each other.

Let us consider some practical examples. Table 3.4 shows some colors and their L*a*b* values. Figure 3.13 shows the positions of these colors in a two- and three-dimensional L*a*b* diagram. Figure 3.13b represents a horizontal “slice” through the three-dimensional solid.

The L^* number tells us how light or dark a color is. While the a^* and b^* tell us about the “color”. Sample #1 is red – it has a large positive a^* value and a positive b^* value. From

Table 3.4 Some example colors and their L*, a*, b* values.

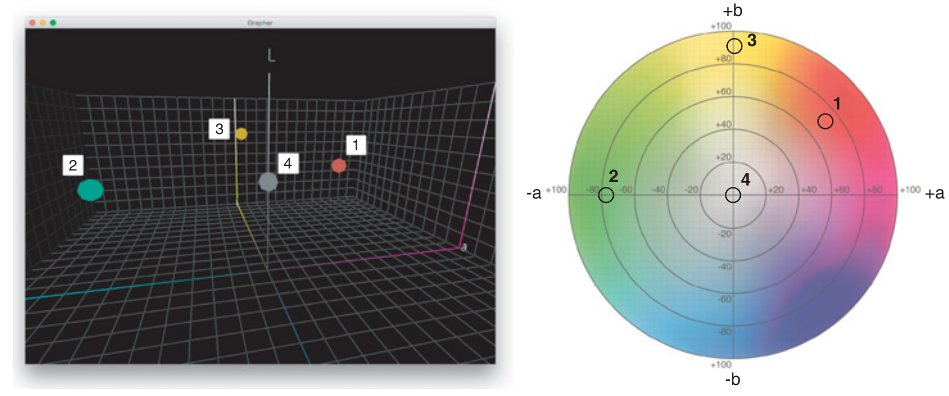
	Color	*L**	*a**	*b**
1	🟥	50	60	40
2	🟩	50	−80	0
3	🟨	70	0	90
4	⬜	50	0	0

the L*a*b* diagram we can see that this represents a red color. Sample #2 has a negative *a** value and small *b**. Thus this color is green. Sample #3 is yellow and therefore has L*a*b* coordinates that place it in the yellow region of the two- and three-dimensional L*a*b* diagram.

We are able to depict the lightness in the three-dimensional diagram, Figure 3.13a. We can comment on the lightness data from Table 3.4. Note that Samples #1 and #2, the red and green, though very different in their color, have identical *L** or lightness. If a color, such as Sample #3 has an *L** of 70, this color is lighter than a color with *L** of 50. Note that the yellow has a high *L** value, which suggests it is very bright. This is typical: we tend to see yellow as very bright, so yellows tend to have high *L**, and we see blue as dark, so blues will generally have a low *L**. A neutral color of the same lightness as the previous examples is Sample #4, with L*a*b* of 50, 0, 0. This neutral gray color has the same lightness as the previous examples but no color, thus *a** and *b** are 0 and in Sample #4 is firmly on the central axis, Figure 3.13b.

The L*a*b* diagram is often used to compare the three-dimensional gamut of two devices, as indicated in Figure 3.14a. A common situation is when RGB camera images will be printed on a CMYK printing process. The larger color gamut of the RGB system means that many colors cannot be realized as they are out of gamut of the print process.

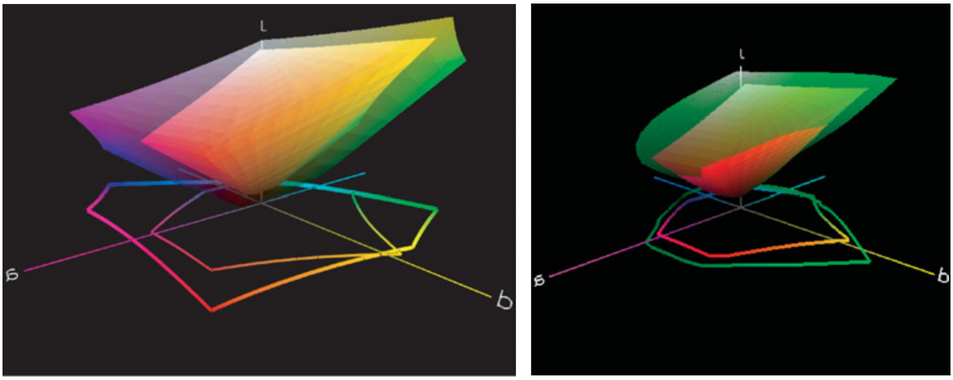
Another application of gamut analysis using L*a*b*, is to confirm the suitability of an inkjet device as a proofer for a press. In this instance we would like the inkjet device to



(a)

(b)

Figure 3.13 The colors described in Table 3.4 are shown in (a) three-dimensional and (b) two-dimensional L*a*b* diagrams.



(a) (b)

Figure 3.14 (a) The color ability of an RGB and CMYK device can be compared using the L*a*b* system, but (b) a two-dimensional projection can be misleading – the "red" device has a gamut that extends beyond the "green" device gamut.

be able to reproduce all the colors that the press can cope with. In an L*a*b* diagram, Figure 3.14b, the proofer gamut (shown in green) should be larger than the press gamut (shown in red). Most inkjet proofers have a good overall match to an offset press, but occasionally there may be dark, saturated colors that the press can achieve that are outside the gamut of the inkjet proofer, as seen in Figure 3.14b. Color is three-dimensional and special care should be taken when analyzing color in two dimensions. Based on the two-dimensional projection alone, we would arrive at the erroneous conclusion that this inkjet proofer was a suitable proofer for this offset press. In color management, if you are trying to examine device gamuts, it is preferable to use a three-dimensional visualization tool.

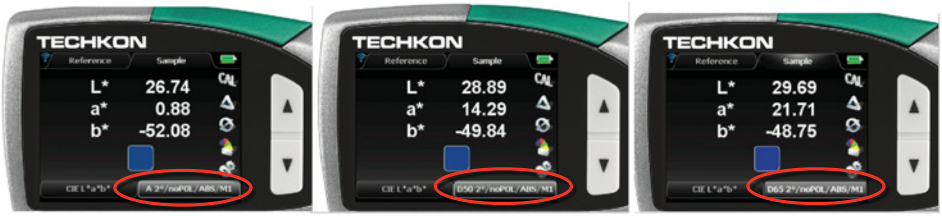
3.7.2 L*a*b* vs. Spectral Data

There is an important difference between spectral data and the CIE metrics that can be derived from spectral data (such as XYZ and L*a*b*).

Spectral data typically consists of 40 numbers at 380, 390, 400, 410 nm,…etc. When we measure a color and compute L*a*b* numbers, this uses less storage space – 40 numbers are reduced to just three. L*a*b* is a more succinct way of describing a color and is one of the reasons why most color management systems use L*a*b*. But L*a*b* numbers are derived from spectral measurements in a non-reversible operation, i.e. we cannot get back to spectral data from L*a*b*.

There are many advantages to retaining and using spectral data. If a sample is measured and retained as spectral data, we can use this to make changes to the assumed measurement conditions and perform re-calculations for new measurement scenarios. The illuminant can be changed from Illuminant A to D50 to D65, and the standard observer, for example, can be changed from 2° to 10°.

To illustrate this principle, a blue sample was measured using a Techkon SpectroDens spectrophotometer, Figure 3.15. The instrument internally retains spectral



L* 26.74
a* 0.88
b* -52.08
A 2°/noPOL/ABS/M1

L* 28.89
a* 14.29
b* -49.84
D50 2°/noPOL/ABS/M1

L* 29.69
a* 21.71
b* -48.75
D65 2°/noPOL/ABS/M1

Figure 3.15 The use of spectral data means that the reference illuminant can be changed from Illuminant A to D50 or D65, without the need to re-measure. Real data from a Techkon SpectroDens instrument display.

measurement data and allows the user to display different L*a*b* values by toggling between illuminants without the need for re-measurement of the sample. Figure 3.15 are real screens from a Techkon SpectroDens instrument and show the effect of switching the light source, primarily in the *a** channel (red color), for a blue sample. This example demonstrates the benefits and flexibility afforded if we retain spectral data for color measurement.

The use of spectral data is very important and is often mentioned in commercial color management solutions that tout their ability to use "spectral data" or offer "spectral color processing". In general the use of spectral data is a good thing as it affords us flexibility and the ability to change parameters and engage in advanced spectral matching processes. As the price of computer storage decreases and computing power increases, we can expect to see an increase in spectral-based color management solutions, especially for expanded gamut and spot color applications.

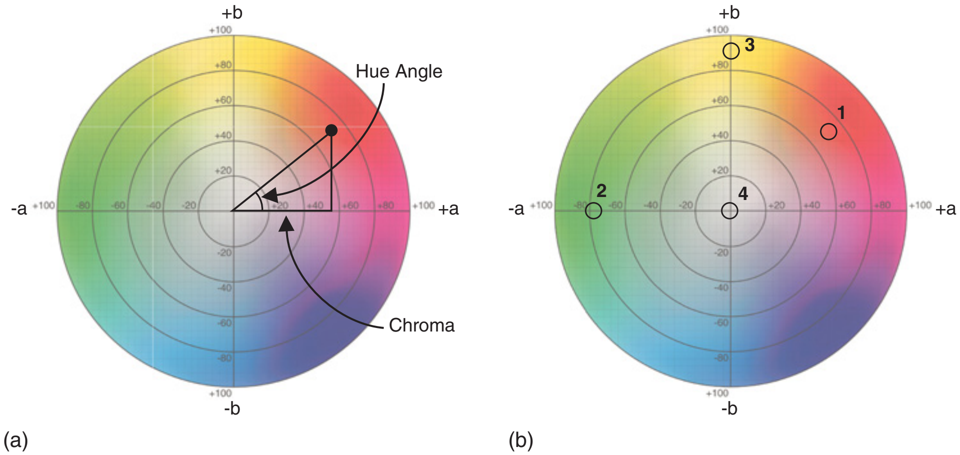
3.8 CIE 1976 L*C*h

A "sister" system to L*a*b* is called L*C*h. The asterisk signifying that this is a CIE approved metric. L*C*h stands for lightness, chroma, and hue. When used individually the coordinates are known as L*, C*, h. You will recall that we need to specify three attributes of color (lightness, chroma, and hue), and the L*C*h system does exactly that.

L*a*b* and L*C*h share the same color space diagram, Figure 3.16. L*a*b* specifies the position of a color on a Cartesian, "rectangular" grid, while the L*C*h system uses polar, "angular" coordinates, but a color is in the same position in both colorspaces.

Let us consider the same samples we used previously and compare how they may be specified in L*a*b* and L*C*h, Table 3.5. The reader can correlate the examples with Figure 3.16.

*L** is exactly the same in the L*a*b* and L*C*h systems, and is the lightness coordinate, which is perpendicular to the plane of the diagram. *C** is the chroma coordinate, the distance from the centre that tells us how saturated a color is. The position around the "circle" is the hue angle (*h*), which is expressed in degrees, with 0° being red, then continuing to 90° for a yellow, 180° for green, and 270° for blue. Readers with a



(a)

(b)

Figure 3.16 (a) L*C*h uses the same diagram as L*a*b* but describes a color in terms of its hue angle and chroma. (b) Four examples from Table 3.5 are shown.

Table 3.5 L*a*b* specification compared to L*C*h specification.

	Color	L^*	a^*	b^*	L^*	C^*	h
1	🟥	50	60	40	50	72	33°
2	🟩	50	−80	0	50	80	180°
3	🟨	70	0	90	70	90	90°
4	⬜	50	0	0	50	0	0°

mathematical slant can use high-school trigonometry to convert from L*a*b* to L*C*h. Sample #1, for example has $C^* = \sqrt{(40^2 + 60^2)} = 72$ and $h = tan^{-1}(\frac{40}{60}) = 33°$.

The L*C*h system is very useful when attempting to visualize issues relating to device gamuts. It is possible to imagine a vertical slice through the L*a*b* color sphere and then consider one-half of that plane. The slice we have just described is effectively similar to one page of the Munsell Book of Color.

The L*C*h system is also used in the design of the IT8.7/2 scanner test targets, Figure 3.17. The targets are constructed in such a way that each row in the target is at a different hue angle. The target is arranged so that rows A–L cover hue angles from 0–360° for a given emulsion type.

3.9 Quantifying Color Difference

It is useful to have the ability to specify color difference by a number. We have already described L*a*b* and L*C*h as numerical ways to specify a color, thus it is a logical extension to use these systems as a basis to numerically specify the difference between

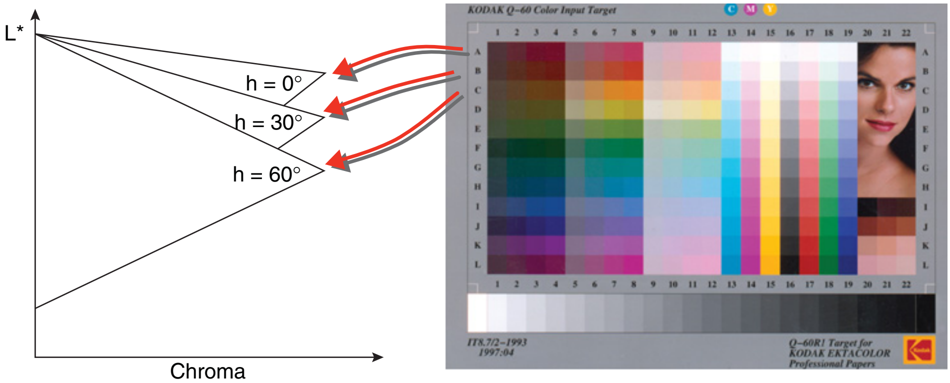


Figure 3.17 The IT8.7/2 scanner target is arranged so that each row A, B, C, is at an increasing hue angle, and together all rows rotate around 360°.

two colors. A numerical measure between two colors is calculated using a metric called Delta E.

Delta E is written as ΔE. The Greek symbol Δ stands for "delta" and is used in scientific literature to represent a difference. The "E" comes from the German word "empfindung", meaning a difference in sensation. Thus the notation ΔE signifies a color difference between two samples. A large ΔE between two samples means that we will see these samples as distinctly different, and a small ΔE suggests that the colors look alike.

Using ΔE, we can say, for example, "the difference between these samples is 4 ΔE." This gives us more useful (quantitative) information than (qualitative) statements such as "these colors do not match" or "this print is too blue." A numerical measure allows setting an easy to determine pass/fail tolerance and also an easy way to define a procurement specification, e.g. we may say that "the print consignment must match the approved sample to within 3ΔE". ΔE is used in many color management applications. In general, we use ΔE whenever we need to talk about the difference between two color samples. We may use it for example to describe the color difference between two press sheets; variation of sheets within a press run; between a press sheet and a proof; between an original and a reproduction, or very commonly to evaluate whether the color patches in a control bar meet a printing standard.

*When ΔE is based on a perceptually uniform color space (L*a*b*) it provides a perceptually related color difference metric.*

3.9.1 Calculating ΔE

We begin this discussion with the simplest form of ΔE called ΔE^*_{ab}. To calculate ΔE^*_{ab}, we measure the L*a*b* of two samples to find their position in L*a*b* space. We then calculate how far apart they are. The distance between the two colors is called ΔE^*_{ab}. Consider an example in which two samples are being compared, Figure 3.18. Suppose we measure the same area in the two samples and obtain L*a*b* values for each. The results are outlined in Table 3.6.

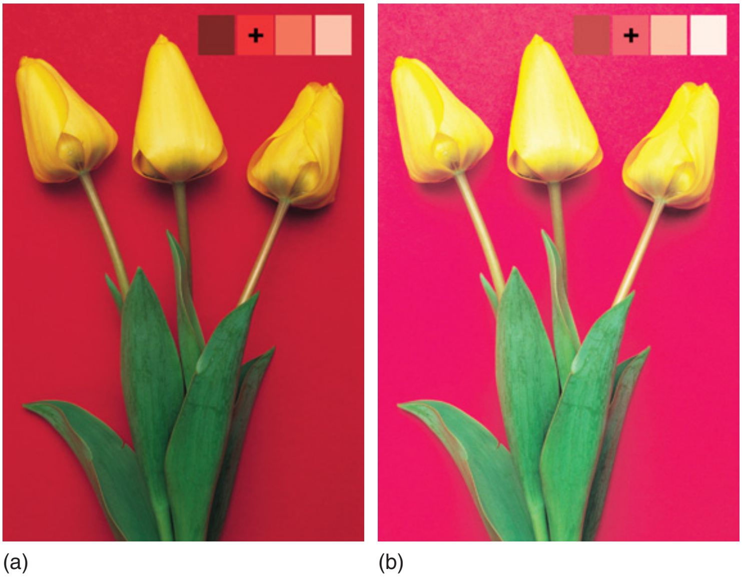


Figure 3.18 To compute Δ*E*, L*a*b* was measured from two samples at the positions shown by the plus sign. The images differ primarily in lightness.

The ΔE^*_{ab} between these two samples is calculated by considering the difference between the respective L^*, a^*, and b^* values. The equation for ΔE^*_{ab} is:

$$\Delta E^*_{ab} = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

here, L_1, a_1, b_1 is the L*a*b* measurement of the original, and L_2, a_2, b_2 is the L*a*b* measurement of its reproduction. The ΔE^*_{ab} for the example is thus:

$$\begin{aligned}\Delta E^*_{ab} &= \sqrt{(56 - 62)^2 + (59 - 58)^2 + (5 - 5)^2}\\ &= 6.08\end{aligned}$$

The ΔE^*_{ab} equation consists of values that are squared and then square rooted, a mathematical trick to ensure that all values are always positive. It is worth noting that once

Table 3.6 Lab measurement of the two colors from the image shown in Figure 3.18.

	*L**	*a**	*b**	Δ*E*
Original	56	59	5	
Reproduction	62	58	5	6.08

ΔE^*_{ab} has been calculated, we no longer have information about the difference in individual L^*, a^*, b^* channels. When assessing colors, or trying to identify the source of errors, it may be useful to calculate separately the color difference in L^*, a^*, or b^*. It is useful for example to know if the difference between the samples comes mainly from a difference in lightness (L^*) or chroma (a^*, b^*). A common procedure is to separate the lightness difference and the chroma difference, using

$$\Delta L^* = \sqrt{(L^*_1 - L^*_2)^2} = \sqrt{(56 - 62)^2} = 6$$

and

$$\Delta C^* = \sqrt{(a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2} = \sqrt{(59 - 58)^2 + (5 - 5)^2} = 1$$

When considering that $\Delta L^* = 6$ and $\Delta C^* = 1$, we see that the majority of the ΔE^*_{ab} clearly is contributed by a difference in lightness. One reason to analyze the separate causes of the color difference is that some corrections are easier to make than others. In this example, the color difference is due mainly to a change in lightness, which may be rather easy to correct simply by increasing ink density.

Another reason to break down the ΔE^*_{ab} equation into its constituent parts is that the human eye is least sensitive to changes in lightness, and more sensitive to changes in chroma. Thus, a color difference due mainly to a contribution of difference in lightness may not be as visually offensive, compared to a similar error that is due to a large difference in chroma.

How do we interpret the ΔE^*_{ab} scale? A ΔE^*_{ab} of 1 is defined as a just-noticeable difference (JND). This is the threshold at which a trained observer would just notice the difference between two colors.

Just because we can see a difference does not mean that the job must be redone. Any press run will vary in its color output from sheet to sheet, from start to finish, and even from left to right of a press sheet. Some variation is normal and acceptable. There is also the concept of perceivable and acceptable color difference. A color difference may be perceived, but the client may agree that it is still acceptable. Tolerances of less than $2\Delta E^*_{ab}$ units are typically unachievable given normal process variations. Even differences between colors in an image that are within $4\Delta E^*_{ab}$ units of each other are acceptable in many situations.

Generally in a commercial printing environment, a ΔE^*_{ab} of 3–6 is deemed acceptable. Each industry sector (such as packaging, automotive, or textiles) may have different general tolerances, and different customers may have specific requirements. A customer could demand a lower ΔE^*_{ab} but must be prepared to pay for the increased cost this will incur. Measuring instruments typically have a repeatability of $0.1\Delta E^*_{ab}$, whereas inter-model differences between vendors may be $1.0\Delta E^*_{ab}$. Due to variation in the printing process and other factors such as instrumentation and human vision, it is generally pointless to try to reduce color differences below $1–2\Delta E^*_{ab}$.

A color difference between two samples, can also be described using the L*C*h diagram, Figure 3.19. Here we see ΔC^*_{ab} describing the difference in chroma between two samples, one sample is further from the centre and therefore more saturated or chromatic. The difference in terms of hue can be defined by ΔH^*_{ab}, that describes the difference between the hue angles of the two samples.

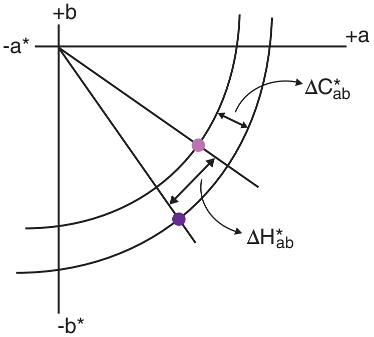


Figure 3.19 The L*C*h diagram can be used to visualize a color difference in hue and chroma. Adapted from Berns 2000, p.73.[2] Reproduced with permission of John Wiley & Sons.

3.9.2 Improved Δ*E* Equations

Scientists and users are aware that the Δ*E* system is not perfect; it performs better in some parts of the color space than in others. Often a visual color difference will not correlate well with a measured color difference. Many of the errors stem from the underlying L*a*b* color space that is not perfectly perceptually uniform.

To illustrate the shortcomings of the simple ΔE^*_{ab} equation, Figure 3.20 shows a set of images with a fixed color difference. The ΔE^*_{ab} is always 6 between the central image and a surrounding image. Our eyes are more sensitive to some color changes. In the figure, for example, we are very aware of the magnitude of color difference in the white blouse and skin tones. We are less sensitive to the same color difference in dark hair and the very saturated red rose. *This leads us to the very important statement that* ΔE^*_{ab} *is more accurate for some colors and less accurate for others.*

There are a number of proposed improvements to the ΔE^*_{ab} calculation. The new versions of ΔE^*_{ab} are still based on L*a*b*; the only thing that has changed is the way in which the calculation is done. The new versions of ΔE^*_{ab} are intended to deal with the issues demonstrated by Figure 3.20, that is we would like a color difference metric that is applicable to all colors. The material that follows briefly reviews some of the newer color differencing equations.

There are different versions of Δ*E* such as: ΔE^*_{ab}, ΔE_{CMC}, ΔE^*_{94}, and CIEDE2000.

We have mentioned that the human eye is less sensitive to changes in lightness and more sensitive to changes in chroma. The Color Measurement Committee (CMC) of the Society of Dyers and Colourists in the UK uses a variation of Δ*E* in their work on textiles and threads. Their modification is called $\Delta E_{CMC(l:c)}$, which improves the prediction for very dark colors and near-neutral colors by introducing two variables, lightness and chroma (*l* and *c*), whose ratio can be varied to weight the relative importance of lightness to chroma. Since the eye will generally accept larger differences in lightness than in chroma a default ratio for *l*:*c* is 2:1. The ΔE_{CMC} calculation was adapted and

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[2] Berns, Roy S., 2000, *Billmeyer and Saltzman's Principles of Color Technology*, 3rd Ed. New York: Wiley-Interscience.

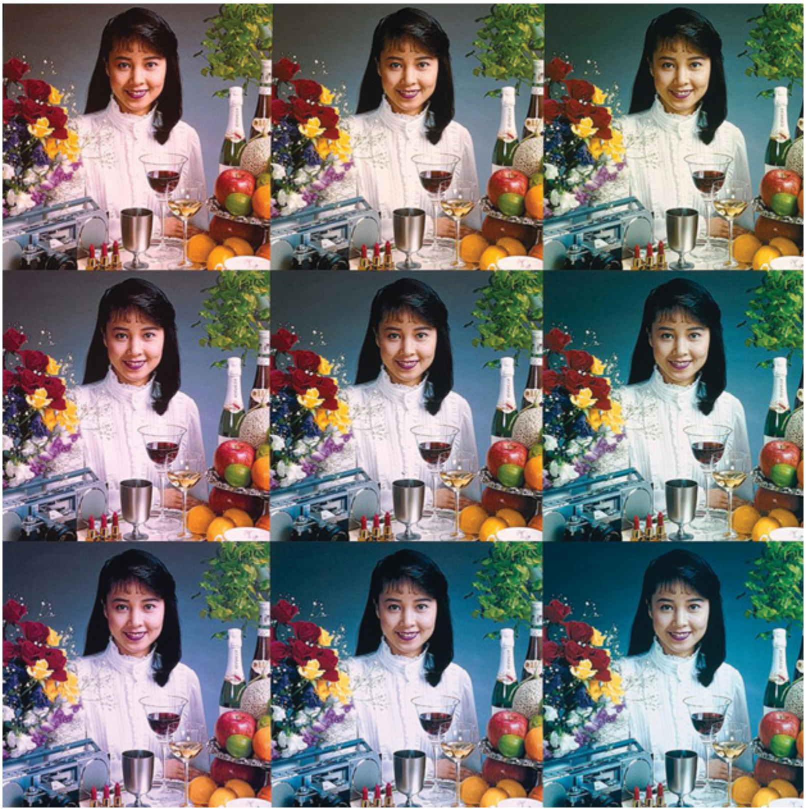

Figure 3.20 There is 6ΔE^*_{ab} between the central image and each adjacent image. The color difference is more apparent in some colors such as skin tones and the neutral background, but is not that obvious in dark, saturated colors such as the red roses or black hair. *Source:* Barco. Reproduced with permission of Barco.

adopted to become the CIE 1994 color-difference equation, bearing the symbol ΔE^*_{94} and the abbreviation CIE94. In 2000, another variation of ΔE was proposed, officially called CIEDE2000.

The newer measures for ΔE are better because they calculate an "elliptical" rather than a "spherical" distance in L*a*b* space. Let us look at what this means.

The L*a*b* of a color can be measured, and thus the color of a sample can be specified by a point in three-dimensional L*a*b* color space, Figure 3.21a. Consider drawing a boundary around this sample that represents a just-noticeable difference. That is, all colors within the boundary are indistinguishable from the sample, and points outside the boundary are seen as a different color. Because of its simplicity, the ΔE^*_{ab} equation draws a perfect sphere around the sample, and this sphere is always the same size, irrespective of what color is being considered. Practical viewing of color samples does not agree with this scenario. For example, a color may fall within the sphere specified by the ΔE^*_{ab} tolerance, and thus we would expect to see no difference between this color and the original sample, yet for some colors we may see a significant difference between the two samples.

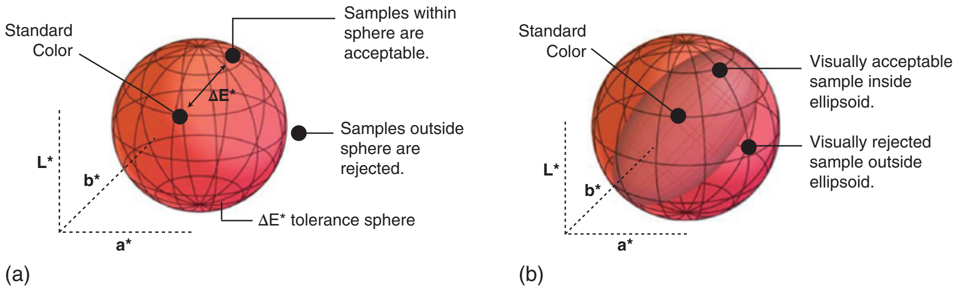
Standard Color
Samples within sphere are acceptable.
ΔE*
Samples outside sphere are rejected.
L*
b*
a*
ΔE* tolerance sphere
(a)
Standard Color
Visually acceptable sample inside ellipsoid.
Visually rejected sample outside ellipsoid.
L*
b*
a*
(b)

Figure 3.21 (a) ΔE^*_{ab} is measured as a fixed spherical distance. (b) A more realistic measure is based on an elliptical volume. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

A more realistic model for human vision describes color differences inside elliptical regions, Figure 3.21b. ΔE^*_{94} and CIEDE2000 are tolerancing methods that calculate "elliptical" measures of color difference, *and the shape and size of the tolerancing ellipse changes dynamically throughout the color space.* The shape and size of the ellipse depends on the color being considered, Figure 3.22. Notice how the tolerancing ellipses are larger near the edges of the L*a*b* space, i.e. we are more accommodating of changes in highly saturated colors, and the ellipses are smaller near the central core because we are very sensitive to small color shifts in near-neutral, gray colors.

We use a practical example to demonstrate the improvements offered by CIEDE2000. Consider two grey patches, Table 3.7. These will usually appear different to the human observer as we are very sensitive to a small change in neutrals colors, so there is correctly about 5ΔE difference between these two patches and both the old ΔE^*_{ab}, and the

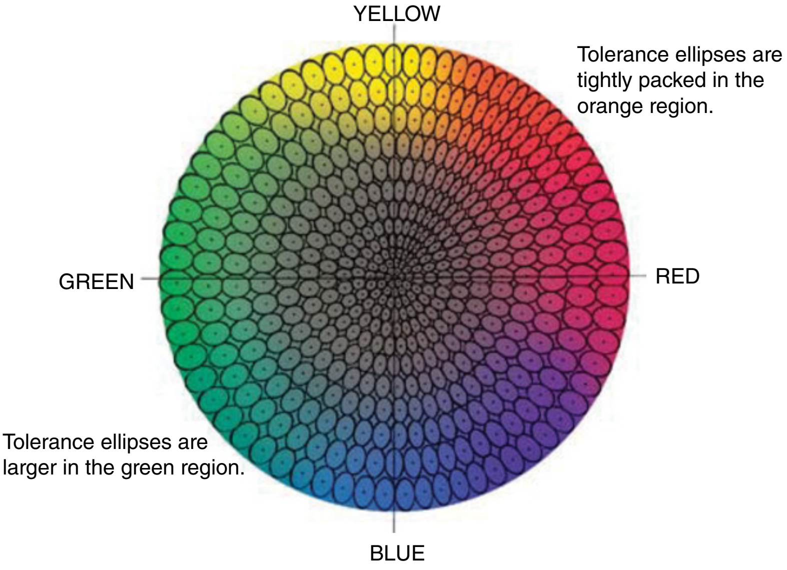
YELLOW
Tolerance ellipses are tightly packed in the orange region.
GREEN
RED
Tolerance ellipses are larger in the green region.
BLUE

Figure 3.22 The tolerance afforded by CIEDE2000 continuously changes size and shape throughout the L*a*b* color space. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

Table 3.7 For some colors ΔE^*_{ab} and CIEDE2000 may be similar, for others CIEDE2000 will be different. CIEDE2000 will be more realistic of perceived color difference as this real example demonstrates.

	▒ ▓	🟨 🟨
ΔE^*_{ab}	5.0	5.0
CIEDE2000	4.5	1.0

newer CIEDE2000 equation predict a similar number. For the yellow patches however, these are very bright and we are not very sensitive to these colors and do not visually perceive a large color difference. The CIEDE2000 equation recognizes our insensitivity, so the CIEDE2000 equation reduces the predicted color difference from 5 to a more realistic number of 1. The CIEDE2000 calculation adjusts, depending on the color under consideration. The reader is able to easily verify this simple experiment.

The newer tolerancing methods provide a better agreement between visual assessment and measured color difference, as shown in Table 3.8, and are therefore regarded in many industries as a more logical and reprentative tolerancing system. Today CIEDE2000 is much preferred and there are only a few instances where ΔE^*_{ab} is used, for example when a standard or specification has not yet been updated to use CIEDE2000, or there is a requirement for compatibility with a legacy application.

3.9.3 Which ΔE Should I Use?

While there is no “right” or “wrong” ΔE equation, the color science community is definitely leaning towards widespread adoption of CIEDE2000. The best equation for you, however, will depend on your application. There are some guidelines that can help you choose an appropriate color differencing methodology.

The relative drift from day to day can be measured and recorded very accurately. Often this “relative” difference may be more useful than “absolute” measurements. For example, in the press room, control limits are most commonly monitored using frequent measurements taken from press sheet color bars. Most new installations of press equipment provide feedback to the operator in units of ΔE via a scanning spectrophotometer (Figure 3.23). It is possible to make in-line or off-line measurements and to display this data in graphs showing press performance trends over time and as a function of ink keys. In such situations, the ΔE change from press sheet to press sheet may provide useful process control information, and the equation used to calculate ΔE is less critical.

Table 3.8 Agreement between tolerancing equations and visual results.

ΔE Equation	**Agreement with visual results**
ΔE^*_{ab}	75%
ΔE^*_{94}	85%
CIEDE2000	95%

Figure 3.23 Press consoles today provide feedback to the operator in units of ΔE.

A ΔE^*_{ab} of 2 is not the same as CIEDE2000 of 2. A very rough approximation is that CIEDE2000 often halves the calculated ΔE, thus for the same pair of colors, you may see that $\Delta E^*_{ab} = 4$, while CIEDE2000 = 2. However, in general, do not try to convert or correlate between equations. Select a single method of calculation and use it consistently. Each equation gives different results, so the best procedure is to pick a single equation and use it in all instances.

Make sure that all departments are using the same color differencing equation. Do not have the prepress department use ΔE^*_{ab} and the press room use CIEDE2000. Always specify which method is being used. It is well accepted that the newer ΔE equations and, in particular CIEDE2000, will give the best correlation between measurement and visual perception and will be most applicable for a wide range of colors from neutrals to skin tones to saturated colors.

3.9.4 ΔE and Images

Although ΔE is very useful as a guide, we should consider a number of other factors that affect the perceived color difference between two samples. Figure 3.24 shows two pairs of images with the same color difference. Our eyes are not that sensitive to the color difference in the "busy" jellybean image. However, the same magnitude of color difference is very noticeable in the large, gray background of the lower image and in the model's skin tones.

These images show us that the instrumental measurement of color and subsequent calculation of ΔE cannot take into account some factors that influence our perception of color. There are a number of such factors that include image size, sharpness, and surface properties such as the difference between matt and glossy paper and between a monitor image and a printed image.

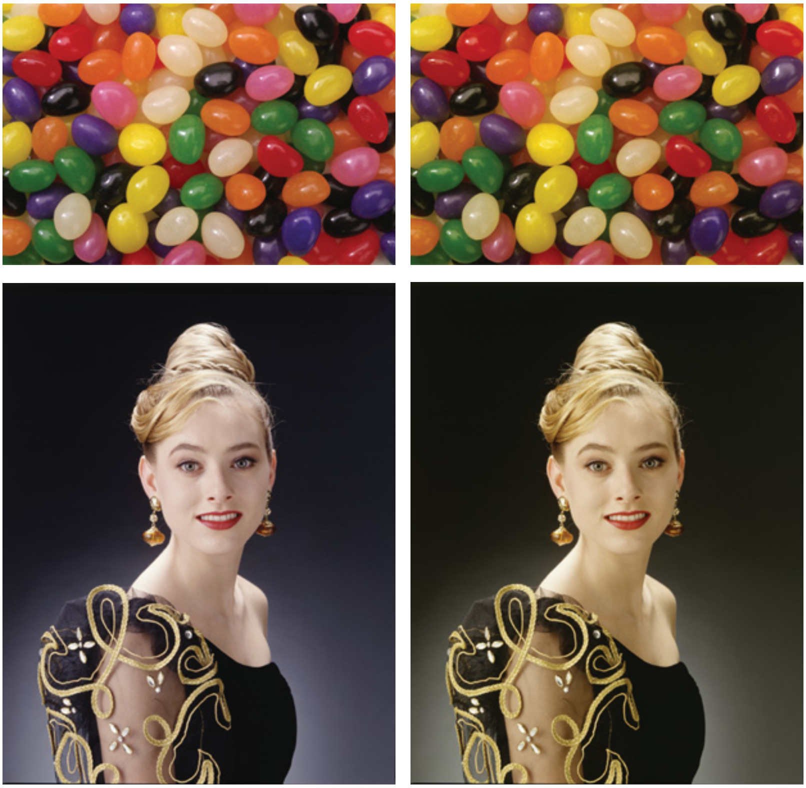

Figure 3.24 There is the same color difference between the top and bottom pair of images. The "busy" jellybean image masks this change, whereas the image of the model with large, near-neutral areas and skin tones, accentuates the color difference.

Another aspect of color evaluation refers to "memory colors", such as green grass, blue sky, red apples, yellow bananas, etc. We have a mental picture of what these items should look like, irrespective of any measured colorimetry.

3.10 Summary

In this chapter we saw that today, color measurement and color management is based on CIE systems that provide numerical measures for color specification and we have moved away from the "variable" human evaluator.

The visual, perceptual attributes of color can be described as lightness, saturation, and hue. We saw that color systems, whether Munsell, Yxy or L*a*b*, may use different terminology, but essentially they all describe the three basic attributes of color.

CIE-based measurements incorporate a calculation that takes into account the light source, the sample, and the human observer. Thus CIE metrics correlate well with human perception, which is part of the reason for their usefulness and wide acceptance in color measurement today. The CIE calculation produces XYZ tristimulus values for a measured color. CIE color spaces like Yxy, L*a*b* and L*C*h, and others, are all transformations of the XYZ measurement.

The Yxy chromaticity diagram was shown to be perceptually non-uniform and also only available as a two-dimensional diagram without a Y axis. The L*a*b* color space introduces a lightness axis and is vastly superior in terms of perceptual uniformity. Three-dimensional L*a*b* color space diagrams are widely used in color management for gamut analysis. A related color space, L*C*h finds favor among some practitioners.

A very important tool in color management is the ability to specify the color difference between two samples by a single number, ΔE. The important point to remember is that ΔE is a good measure to use because it is based on what we see: it is not just a numeric metric, it is a *perceptually-relevant* numeric metric.

Ongoing color science research has given us different equations for ΔE, and some of the newer equations were examined in this chapter. We saw that the newer ΔE metrics, such as CIEDE2000, are "dynamic," which means that they change depending on the color pair that is being considered.

ΔE however, should not be used alone because there are situations in which the image content can affect our perception of color difference. For example, we compared color differences in a "busy" image to differences in an image with skin tones and large, near-neutral regions.

CIE systems provide the whole framework for color management, and are frequently referred to throughout the remainder of this text.

4

Measuring Instruments

Objectives

- Describe the three main categories of measuring instrument: densitometer, colorimeter, and spectrophotometer.
- Review popular instrument types, such as the X-Rite i1Pro2 spectrophotometer.
- Describe new, UV-related, M0, M1, M2, M3 measurement modes.
- Evaluate new generation smartphone and other low-cost systems.
- Explain inter-instrument and inter-model measurement differences.

4.1 Introduction

To manage color we need to measure color. Since the human visual system cannot assign numerical values to a sample, color management is very reliant on instrument-based measurement. Measuring instruments provide a numerical and repeatable way to measure color. Modern instruments calculate CIE-based color metrics such as XYZ and L*a*b*, which are the mainstay of color management today.

Many color management processes use a measuring instrument. To make a profile you need a measuring instrument. To view an image on a screen the monitor should be calibrated, usually with a colorimeter. During a press run it is necessary to measure press sheets to ensure there is no drift. After a major component replacement on a digital press, or media roll on an inkjet proofer, we must ensure the device is operating within tolerance. As we present the customer the final job we can measure control patches to ensure we meet the agreed target values. All these instances require a measuring instrument.

Recently color management has benefited by advances in instrument quality and price. Over the last few years considerable progress has been made in instrument design and manufacture, for example, the white calibration tile is now often integrated within the instrument casing. Most instruments today have a convenient computer interface for automated capture and storage of measurement data. Today we have more reliable instruments, stable readings, and devices that are faster, lighter, and easier to use. Perhaps the biggest boost to color management implementation is the affordability of today's measurement devices.

Understanding Color Management, Second Edition. Abhay Sharma.
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In order to deal with the phasing out of CRT monitor technologies in favor of flat-panel displays there are a number of new developments in the colorimeter market for monitor profiling, as described in this chapter.

A major recent development is an international standard – ISO 13655 – that describes the M0, M1, M2, M3 measurement modes. These modes clarify how devices should operate which helps eradicate many problems associated with ultraviolet fluorescence. All manufacturers have been busy updating or releasing new instruments that meet ISO 13655. This chapter describes in detail the new M0–M3 measurement modes.

An exciting area is the new generation of low-cost instruments that use a small physical sensor and an iPhone or Android device. A number of new instruments were tested and rated in terms of CIEDE2000.

To decide what instrument you need, you need to know what your requirements are. This includes knowing what types of profiles you want to make, how often you want to make them, and whether you are operating at a home-office level, professional photography level or commercial prepress level. Your choice of instrument should consider the following issues.

- *Instrument type*: Densitometer, colorimeter, or spectrophotometer?
- *Instrument modes*: Measuring emission (monitor), transmission (film), reflection (print), or ambient light (such as a light booth)?
- *Instrument operation*: Single hand-held device, automated chart scanning, automated xy table, press-side offline or inline device?
- *Measurement modes*: How does the device measure UV? Does the device have the options of M1 and M2?

This chapter looks at some commercially available instruments and helps you decide on which device is best for your situation.

4.2 Instrument Types

Instruments can be divided into three main types, depending on how they operate and what they can measure, Table 4.1. A *densitometer* is a basic quality-control measurement device optimized for photographic and printing applications. Densitometers can be used to measure film, printing plates and press sheets. A densitometer measures density. Density is not a CIE-type color metric and therefore densitometry is only indirectly used in color management, densitometers can be used to arrive at controlled or standard press conditions and also to measure metrics such as dot area and dot gain.

Table 4.1 There are three main types of measuring instrument – densitometer, colorimeter and spectrophotometer. Spectrophotometers form the most versatile instrument category.

	Density	XYZ/L*a*b*	Spectral Data
Densitometer	✓	–	–
Colorimeter	–	✓	–
Spectrophotometer	✓	✓	✓

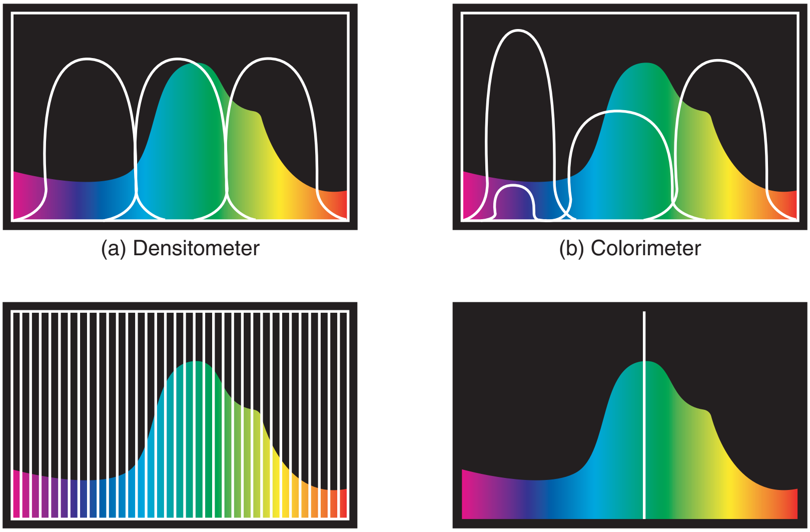
A *colorimeter* can measure and compute CIE-type color metrics and can be used to measure the XYZ values of a sample. Colorimeters usually also report measurements derived from XYZ, such as Yxy and L*a*b*. Colorimeters are light, compact, reliable, and inexpensive devices. In color management, colorimeters are used to measure desktop monitors, laptop screens, flat-panel displays, projectors and tablet and smartphone devices.

The most complete type of color measurement is achieved with a *spectrophotometer*. A spectrophotometer measures the spectrum of a sample, reporting the reflectance or transmittance of the sample. The spectrum is the most complete descriptor of a color, and it can be used to calculate all other metrics, such as XYZ and L*a*b* and density.

Today color management is based on CIE-type color metrics – you need to be able to measure or compute minimally XYZ or L*a*b*. Thus, to implement color management it is necessary to have at least a colorimeter, and preferably a spectrophotometer.

4.3 Instrument Filter Bands

To understand the distinction between the instrument types, let’s look at how each device operates. A densitometer, Figure 4.1a, has filters that sample the red, green, and blue parts of the spectrum. The shape of the filter response curve is matched to the type of material to be measured, such as photographic dyes or printing inks. When a densitometer is matched to process inks it may not be suitable for non-standard materials, such


(a) Densitometer

(b) Colorimeter

(c) Spectrophotometer

(d) Spot Color

Figure 4.1 Each instrument type has a different measuring system. (a) A densitometer has a response that corresponds to printing inks. (b) A colorimeter is designed to have a response similar to that of the standard human observer. (c) A spectrophotometer measures the full spectrum. (d) Spot colors can be measured based on their maximum absorption.

as spot color inks or metallic inks. Unlike other color metrics, density is based on very little post-processing of the measurement data and is a number related to the amount of light measured through each of the filters. Densitometers do not take into account the color of the illuminant or aspects relating to the human perception of color. Thus density does not provide measurements that correlate well with the human perception of color therefore density should only be used for process control.

A colorimeter, Figure 4.1b, is pre-loaded with filters that create the human observer function, so via this neat trick, *a colorimeter can directly produce CIE metrics*, such as XYZ, and other derived values, such as L*a*b*.

A spectrophotometer does not measure the sample using any particular filter band; instead it measures the sample's full spectrum, Figure 4.1c. When reporting spectral data, the instrument will typically report the spectrum every 10 nm, irrespective of the increments at which the spectrum was actually measured.

A spectrophotometer can be used in special cases to measure the density of a non-standard material, for example a spot color, in this instance the peak absorption wavelength is dynamically determined, Figure 4.1d.

A spectrophotometer can mathematically create a filter response as shown by the other graphs, and therefore a spectrophotometer can provide all the measurement values of a colorimeter or a densitometer, but not vice versa. In instances where a spectrophotometer is used to report XYZ, it may be called a spectro-colorimeter. When a spectrophotometer is used to compute density, it is often called a spectro-densitometer.

4.4 Densitometers

Density is a measure of the amount of light reflected from a sample. The printing industry has traditionally used density for measurement at press side because as you lay down more ink the measured density increases, so we have a direct correlation between measured density and ink on press.

There are two methods to measure density: with a densitometer that uses filters, i.e. a *filter densitometer*, or more commonly today, computed mathematically by a spectrophotometer that measures the sample's spectrum, a *spectro-densitometer*. Densitometers can be used to manually read a single sample in transmission or in reflection, traditional densitometers (non-spectral devices) are shown in Figure 4.2.

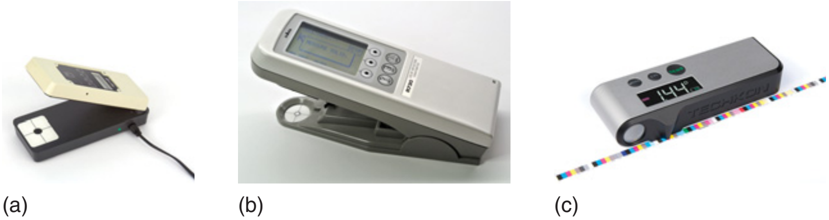

(a) (b) (c)

Figure 4.2 Traditional filter-based densitometers (a) X-Rite 341C portable transmission densitometer for film. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated. (b) Ihara R730 handheld reflection densitometer for printed samples. *Source:* Ihara. Reproduced with permission of Ihara, Incorporated. (c) TECHKON DENS reflection densitometer and film transmission densitometer. *Source:* TECHKON GmbH. Reproduced with permission of TECHKON GmbH.

4.4.1 Density Equation

It is possible to define transmitted density and reflected density. In regards to transmission, density is the ratio of incident light to transmitted light. In regards to reflection it is the ratio of how much light is incident on the sample compared to how much light reflects back. Reflected or transmitted light is collected through filters and at different imaging geometries. Stated mathematically, density is:

$$D = log\left(\frac{I_i}{I_t}\right) \quad \text{or} \quad D = log\left(\frac{I_i}{I_r}\right)$$

where D is density, I_i is the intensity of incident light, I_t is the intensity of transmitted light, and I_r is the intensity of reflected light.

The unit of density is called optical density or simply "density". As density is a measure of reflected light compared to incident light it is a ratio and therefore has no units, being denoted, for example, as 2.0 D or simply "a density of 2.0." A typical reflection densitometer may have a range of 0.05–3.0, whereas a transmission densitometer can deal with densities in the range of 0.05–6.0.

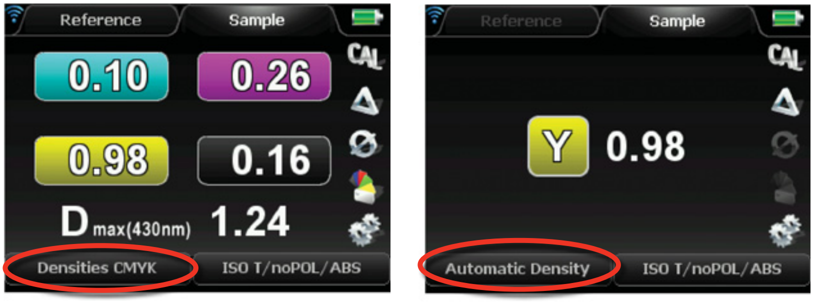
Note that the density equation involves a log function. After measuring the ratio of incident to transmitted light the densitometer performs a logarithmic calculation. The log function is used in an attempt to make the measurement more akin to the way the human eye responds to changes in lightness. Thus densitometry makes a limited attempt to model human perception.

4.4.2 Status Densitometry

Density uses red, green, and blue filters to measure the complementary colors cyan, magenta, and yellow. (A filter complementary to the color being measured is used so that there is no "color" left in the reflected/transmitted light.) Black ink is not spectrally selective, and therefore a wide-band filter is used to measure neutral density. Thus we can say that densitometers measure only the "amount" of light and not any color characteristics.

Densitometers always use red, green, and blue filters. However, as they are used to measure the complementary colors (cyan, magenta, and yellow) the labels in a densitometer may be labeled C-M-Y-K. Historically, a filter wheel was switched manually, but it is more common in the modern generation of densitometers (and spectrodensitometers) to have this function performed within the device software. An instrument can display the density of a sample via all "filters", Figure 4.3a, or automatically determine and display only the density of the primary channel in the sample, Figure 4.3b.

To make sure all instruments report the same measurement, the American National Standards Institute (ANSI) and ISO (International Organization for Standardization) has specified a series of response curves (called ANSI/ISO Status classifications) that ensure consistency in densitometer readings. The main spectral responses are Status A and M, which are used for photographic purposes; Status T, used for North American graphic arts; and Status E, used for European graphic arts. These Status responses are implemented via different shaped curves. The selected Status is usually shown in the instrument display; for example see ISO T being used in the lower right of Figure 4.3a.



(a) (b)

Figure 4.3 Techkon SpectroDens display showing (a) all the CMYK density measurements for a sample or (b) automatically displaying the primary density channel.

If you are measuring non-process inks, you should try each filter (cyan, magenta, and yellow) and use the one that gives the highest, most responsive reading, or use the spectral density mode, Figure 4.1d.

4.4.3 Density and Process Control

While densitometry cannot directly measure color, per se, there are some color-related applications where density is used. Density can be used in color management to arrive at a controlled or standard press condition, such as that determined by Specifications for Web Offset Publications (SWOP). The SWOP document specifies, for example, that on Grade 5 coated paper the solid ink patches on a press sheet should have a density of C = 1.30, M = 1.40, Y = 1.00, and K = 1.60. If your press conforms to these and other specific requirements and is judged to be visually acceptable, your print process is in accordance with the SWOP specification. So densitometers are not directly used in color management, but they can be used to establish standard press conditions.

Another use for densitometry is in measurement of *dot area* and *dot gain*, now called *tone value* and *tone value increase* (TVI). In printing systems that use halftone dots, it is useful to estimate the dot area of the sample. Density measurements can be used to calculate dot area. From dot area, it is possible to calculate dot gain as the difference in dot area between any “before” and “after” process. The dot area of a sample is calculated from density measurements, using the Murray–Davies equation,

$$Dot\ Area = \frac{1 - 10^{-D_t}}{1 - 10^{-D_s}} \times 100$$

where D_t is density of the tint and D_s is density of the solid. Note that D_t and D_s are measured minus paper. The user does not have to manually compute the Murray–Davies equation as today it is handled internally by all instruments.

A dot gain curve is often used to understand and monitor the press response across the tonal range (from 0–100%) and the relationship between the individual CMYK channels, Figure 4.4. In offset printing, blanket packing or over-inking can cause an increase in dot gain. It is generally required that the color channels have similar dot gain curves, to avoid a color cast in the printed image.

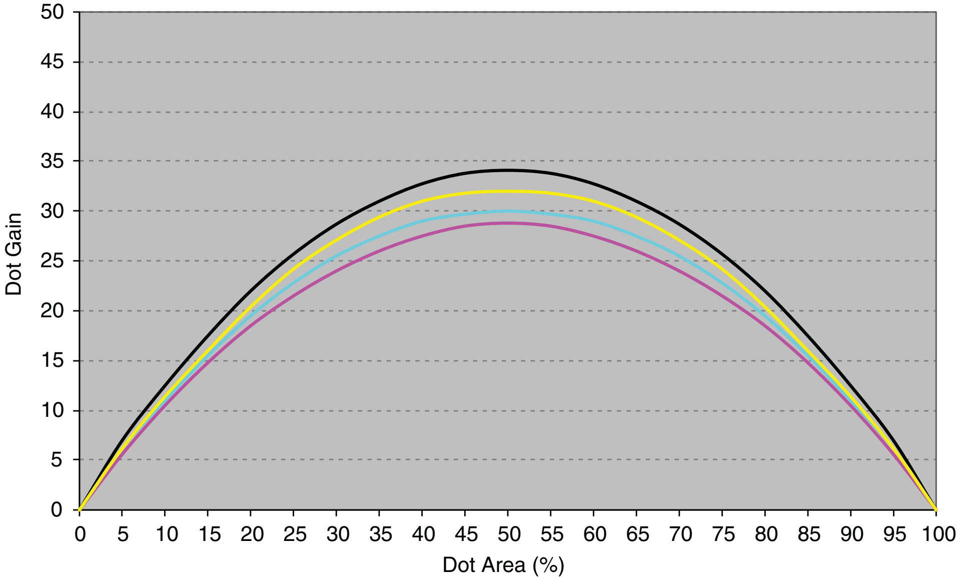


Figure 4.4 Dot gain curves can be used to monitor the printing response of a C-M-Y-K print process. To avoid a color cast in the printed image, individual channels should have similar curves.

Whereas density has traditionally been used in pressroom operations, the trend in all new press installations is for control via instruments that can provide CIE color metrics.

4.5 Colorimeters

Colorimeters are compact, lightweight, and relatively inexpensive color-measuring instruments. The main use for colorimeters in today's color management scenarios is to make profiles for all forms of flat-panel displays and recently for mobile devices, Figure 4.5. A photographer may only want to make display-type profiles, in which case it is possible to buy a colorimeter for less than $300. Colorimeters, examples of which are shown in Figure 4.6, come in different shapes and sizes. Today these devices offer many useful features. Datacolor's Spyder5 device, offers an integrated light sensor that can measure your room lighting and alert you if there's been a change in ambient light levels. X-Rite devices offer a display control technology that automates the adjustment of the display's hardware (brightness, contrast, and color temperature) to speed up the profiling process and eliminate manual adjustments. Colorimeters can be used in reflection mode to make printer profiles, one commercial solution is the Datacolor SpyderPRINT system, Figure 4.6c.

4.5.1 Filter-based Colorimetry

There are different classes of colorimeters, with lower cost, filter-based colorimeters being used in everyday color management. Filter-based instruments use at least three

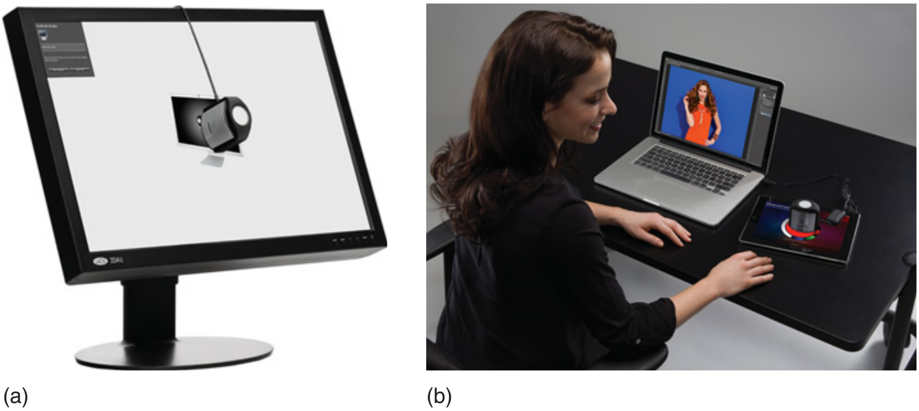
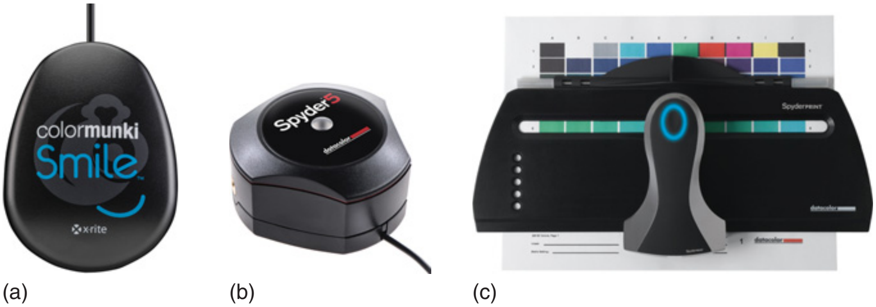

(a) (b)

Figure 4.5 The X-Rite i1Display Pro is a colorimeter that can be used to (a) profile flat-panel displays and (b) tablet devices via tethered control. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

filters behind each of which is a photodetector photocell, usually some sort of photodiode. The important aspect of a colorimeter is that the system has a *response equal to that of the CIE standard observer*, so that the instrument directly measures XYZ. From the XYZ values, the software can easily determine other color metrics, such as L*a*b* and Yxy. The measurement configuration means that colorimeters cannot record density or spectral data; they only provide XYZ values.

One of the challenges facing colorimeter manufacturers relates to the phenomenon depicted in Figure 4.7a, which is a second, smaller bump in the standard observer's red response curve. The red response function has some sensitivity in the blue part of the spectrum. One of the issues with colorimeter design is creating a system that can detect this small bump in the blue part of the spectrum.

We notice that the two peaks in the blue region are of significantly different heights, so a manufacturer can seek to record this additional peak by having a separate, fourth



(a) (b) (c)

Figure 4.6 Commercial colorimeters for display calibration include (a) X-Rite ColorMunki Smile, and (b) Datacolor Spyder5 with ambient light sensor. (c) The SpyderPRINT is the only commercial colorimeter for printer calibration. Image (a) *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated. Images (b) and (c) *Source:* Datacolor, 2017. Reproduced with permission of Datacolor.

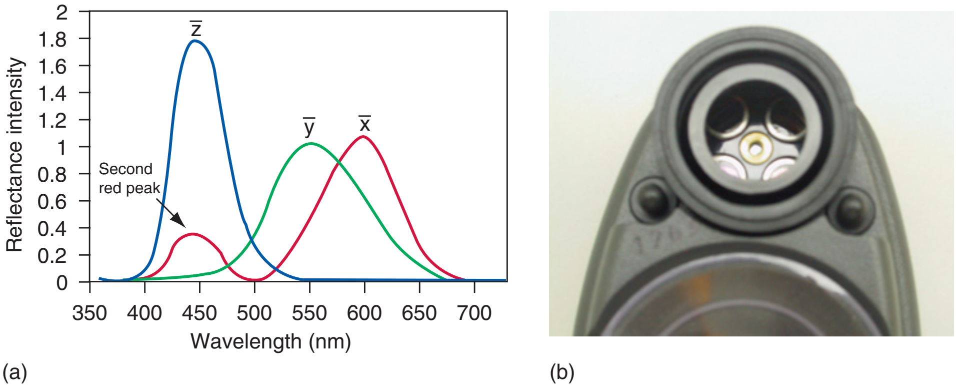


Figure 4.7 (a) The standard observer function has three primary peaks, but the red channel has a smaller fourth peak. (b) The fourth filter in a colorimeter can be used for the second red peak.

filter solely dedicated to sampling the small red bump. Thus, colorimeters can have four filters, as shown in Figure 4.7b.

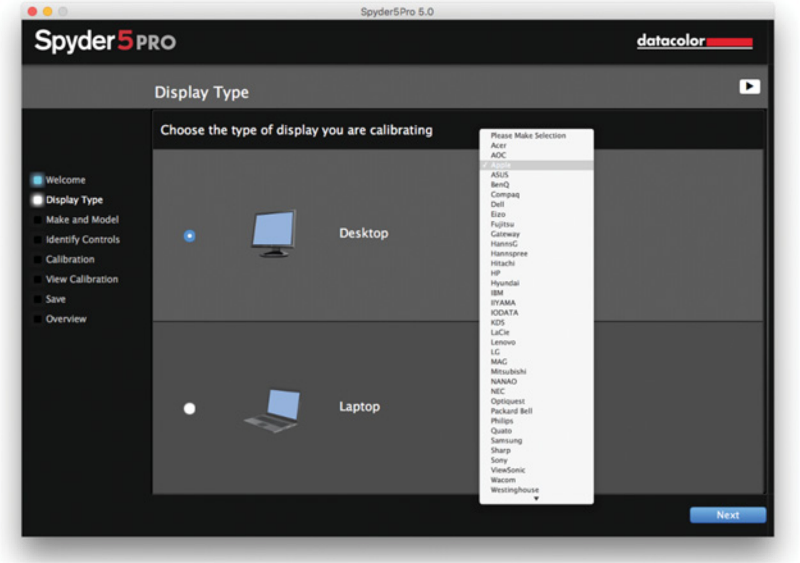
4.5.2 Improvements in Display Colorimeters

It is difficult to manufacture and implement filter materials that exactly match the CIE color matching functions – at an affordable price. In order to address this issue, manufactures have traditionally created a system that has the *overall* effect of the color matching functions. In other words, the filters within the instrument when combined with the display characteristics together create a close match to the CIE color matching functions. A colorimeter manufacturer can assume a nominal display type and build into the instrument an appropriate computation, so that when used in practice the overall result approximates the CIE color matching functions.

This approach worked well when CRT phosphor-based devices were the main display type. When there was a single display type, all displays had essentially similar RGB phosphor primaries and this information was used to create the math for the color matching function calculation. Today however, there are a number of different display technologies and the lamp types within these display systems have wide ranging color characteristics. The light source in LCD (liquid crystal) displays can be a CCFL backlight, an LED backlight, OLED backlights, wide gamut LEDs, expanded gamut phosphors, etc. And there are other types of displays, e.g. plasma displays. Colorimeters can be used to measure projector systems, and there is also variation in projector systems, such as those that use a sector wheel and 1-chip DLP vs 3LCD technologies. Colorimeters can be used to measure smartphone and tablet devices.

In order to improve the accuracy of filter-based colorimeters it is possible to consider the specific display being measured, Figure 4.8. By providing information about the display's light source to the instrument, a user can expect greater measurement accuracy.

There are different ways to include account for the characteristics of the display – the user can select the display type from a drop-down menu, software can interrogate the display for a display model identification tag, or a custom measurement file can


Spyder5Pro 5.0
Spyder5PRO
datacolor
Display Type
Welcome
Display Type
Make and Model
Identify Controls
Calibration
View Calibration
Save
Overview
Desktop
Laptop
Please Make Selection
Acer
AOC
✓ Apple
ASUS
BenQ
Compaq
Dell
Eizo
Fujitsu
Gateway
HannsG
Hannspree
Hitachi
HP
Hyundai
IBM
IIYAMA
IODATA
KDS
LaCie
Lenovo
LG
MAG
Mitsubishi
NANAO
NEC
Optiquest
Packard Bell
Philips
Quato
Samsung
Sharp
Sony
ViewSonic
Wacom
Westinghouse
Next

Choose the type of display you are calibrating

Figure 4.8 To deal with a wide range of display types, Datacolor's Spyder5 system is customized to the flat-panel's specific make and model.

be loaded. Via these processes, by fine-tuning the measurements to the display's light source, a new generation of colorimeters have enabled better color measurement accuracy across a wider range of display types.

4.6 Spectrophotometers

Today, spectrophotometers are the instrument of choice for all aspects of color management. In the past, a spectrophotometer was a less favored instrument. Spectrophotometers used to be slow, bulky, and expensive laboratory devices. A spectrophotometer would painstakingly scan the spectrum every 1 nm, a time-consuming operation. Today, these devices are small, inexpensive, and fast. A wide range of spectrophotometer models are available from different manufacturers and in different configurations, creating a very competitive landscape, Figure 4.9. Every device shown in this graphic is reliable, accurate, computer controlled, and will report measurements in accordance with current ISO standards.

A spectrophotometer can offer a *spot mode*, where an individual spot measurement is taken, perhaps to check whether the print sample meets target values. *Scanning* devices are able to read a large number of color patches in a short period of time. *Table* devices move over the substrate and are able to accommodate thicker and/or rigid media. The distinction of "spot-scanning-table" is a somewhat arbitrary classification and many devices, for example the X-Rite i1Pro2, could neatly fit in all three categories.

Commercial spectrophotometers operate by splitting light into its component colors and measuring how much there is at each wavelength. Light arriving at an instrument from the sample, is split into component colors by a diffraction grating. A diffraction

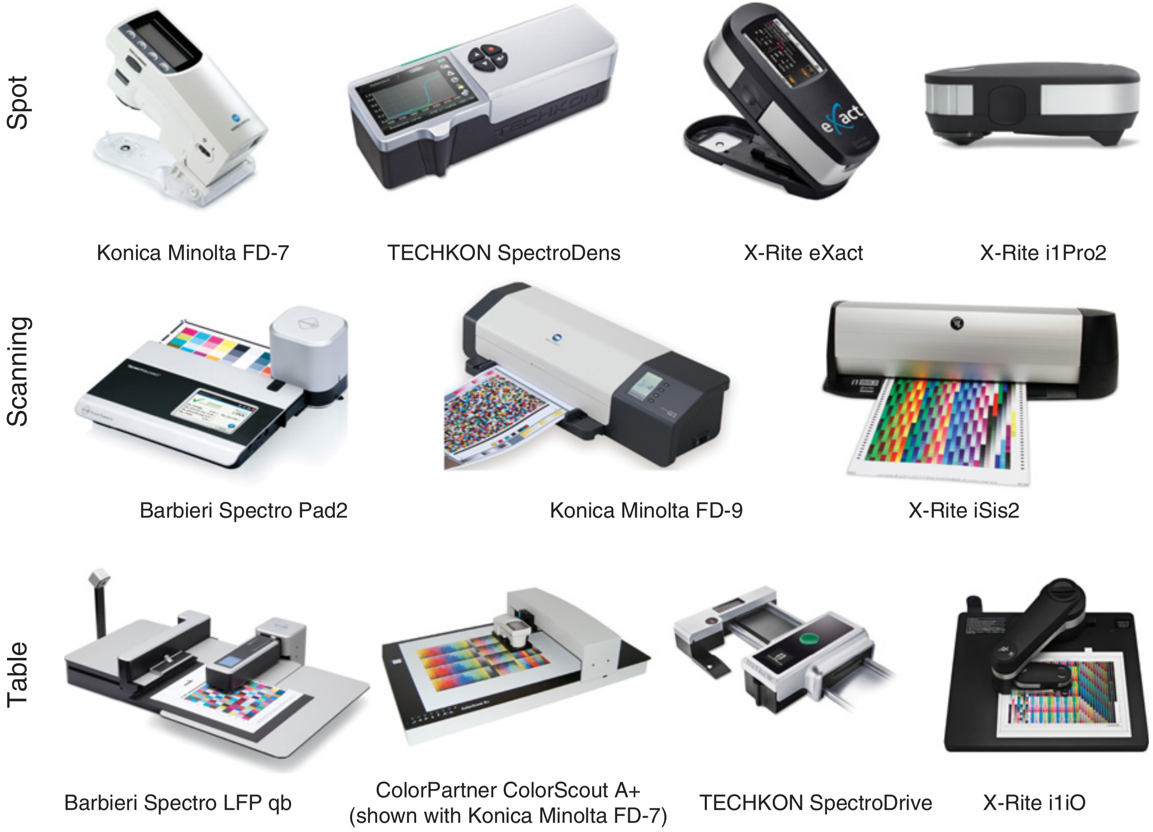
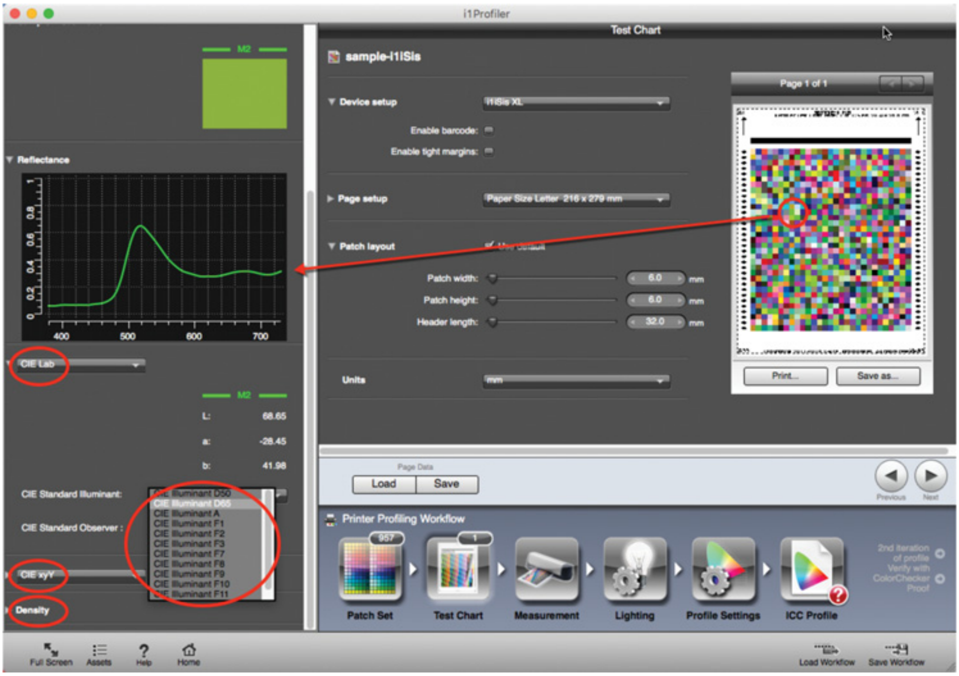

Spot
Konica Minolta FD-7
TECHKON SpectroDens
X-Rite eXact
X-Rite i1Pro2
Scanning
Barbieri Spectro Pad2
Konica Minolta FD-9
X-Rite iSis2
Table
Barbieri Spectro LFP qb
ColorPartner ColorScout A+
(shown with Konica Minolta FD-7)
TECHKON SpectroDrive
X-Rite i1iO

Figure 4.9 Commercial spectrophotometers are available as spot, scanning or table type devices. All devices shown are M1 compliant. Reproduced with permission of Barbieri, ColorPartner, Konica Minolta, TECHKON GmbH, X-Rite Incorporated.



sample-i1ISis

Device setup: i1iSis XL

Enable barcode: ☐

Enable tight margins: ☐

Page setup: Paper Size Letter 216 x 279 mm

Patch layout: ☑ Use default

Patch width: 6.0 mm

Patch height: 6.0 mm

Header length: 32.0 mm

Units: mm

CIE Lab

L: 68.65

a: -28.45

b: 41.98

CIE Standard Illuminant:

CIE Standard Observer :

i1Profiler
Test Chart
M2
Reflectance
1
0.8
0.6
0.4
0.2
0
400
500
600
700
CIE Illuminant D50
CIE Illuminant D65
CIE Illuminant A
CIE Illuminant F1
CIE Illuminant F2
CIE Illuminant F3
CIE Illuminant F7
CIE Illuminant F8
CIE Illuminant F9
CIE Illuminant F10
CIE Illuminant F11
CIE xyY
Density
Page 1 of 1
Print...
Save as...
Page Data
Load
Save
Previous
Next
Printer Profiling Workflow
957
1
Patch Set
Test Chart
Measurement
Lighting
Profile Settings
ICC Profile
2nd iteration of profile
Verify with ColorChecker Proof
Full Screen
Assets
Help
Home
Load Workflow
Save Workflow

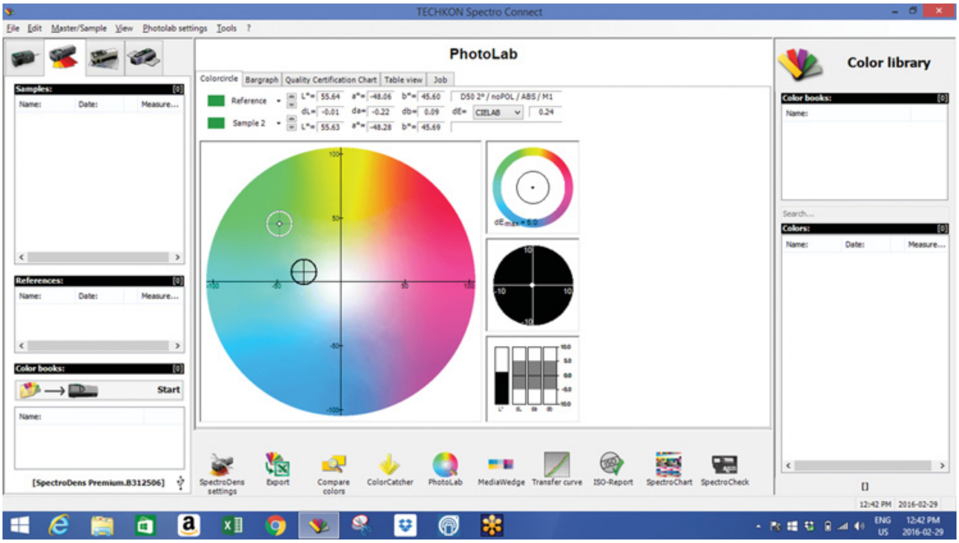
Figure 4.10 A spectrophotometer can measure the spectral data for each patch of a test target, which allows the user to change the reference illuminant, and compute any metric such as Yxy, density, etc. Software shown is X-Rite's i1Profiler.

grating is a glass slide containing many narrow, closely spaced vertical lines. Light is diffracted by the lines and dispersed into the "rainbow" of colors. The dispersed light is focused onto a photodetector array, and by considering the position of each photodetector and the amount of light falling on it, it is possible to determine the sample's spectrum. The spectrum is usually measured from the near ultraviolet to the visible range, usually from around 380–730 nm. If spectral data is retained during measurement, it is possible for software to re-calculate the color of the sample as if illuminated or seen under a different illuminant, Figure 4.10.

Spectral data is used in any application that requires color formulation relating to ink pigments, fabrics, or dyes. An example of this is a commercial paint-mixing system. Your local hardware store may have a spectrophotometer that is linked to prediction software. When you want a paint mixture that will match a sample, the sample is measured and the software calculates the most efficient proportions of base paints that can be mixed to produce an accurate match. The only way this type of analysis can be done is with spectral data.

4.6.1 Spectrophotometer Features and Functions

In terms of physical measurements, all instruments shown in Figure 4.9 will measure in reflection mode (printed samples). In addition, some instruments (e.g. Konica-Minolta FD-7) will measure ambient light or a viewing booth.


TECHKON Spectro Connect
File Edit Master/Sample View Photolab settings Tools ?
Samples:
Name: Date: Measure...
References:
Color books:
Start
[SpectroDens Premium.B312506]
PhotoLab
Colorcircle
Bargraph
Quality Certification Chart
Table view
Job
Color library
Search...
Colors:
SpectroDens settings
Export
Compare colors
ColorCatcher
PhotoLab
MediaWedge
Transfer curve
ISO-Report
SpectroChart
SpectroCheck

Reference L*= 55.64 a*= -48.06 b*= 45.60 D50 2° / noPOL / ABS / M1

dL= -0.01 da= -0.22 db= 0.09 dE= CIELAB 0.24

Sample 2 L*= 55.63 a*= -48.28 b*= 45.69

Figure 4.11 TECHKON Spectro Connect PC software is used to capture data from a TECHKON SpectroDens instrument.

Some instruments can measure emissive light and therefore be used to calibrate flat-panel displays (X-Rite i1Pro2) and with an appropriate holder, the same device can be used to measure a projector. The only device able to operate in transmissive mode for film materials is the Barbieri Spectro LFP RT, released at the 2016 Drupa trade show. For rigid or thick media, a table device can be used to accommodate the height of the media (Konica-Minolta with ColorScout, TECHKON SpectroDrive, X-Rite i1iO).

In most cases, profiling or other color management software will communicate directly with the instrument, leaving the user to follow instructions for calibration and measurement. All of the instruments can also be controlled via their own driver software via a computer interface, Figure 4.11. The seamless integration of instrument and profiling software, and the widespread third party support and connectivity, have fueled the rapid growth in the use of spectrophotometers in color management.

When spectrophotometers are used to compute CIE metrics, it is necessary to specify some basic parameters. It is necessary to be able to specify the CIE Illuminant (D50, D65, Illuminant A, etc.) and the 2° or 10° standard observer. All spectrophotometers must support these basic settings. In addition devices may support density and dot gain calculations. Graphical display of data, including L*a*b* diagrams and spectral graphs are useful features that allow visualization and assist in interpretation of measured values.

The typical measurement geometry for commercial spectrophotometers is “45/0”, which refers to the angle of incident light and measured light, respectively. This is the normal measurement system for everyday applications, while scientific and technical applications or other special situations may require a different measurement geometry.

An instrument can create measurements in different measurement modes. If purchasing a new device it must offer at least the M1 measurement mode and, using filters or switches, be optionally interchangeable to operate in M0, M2, or M3 modes, to be discussed shortly.

Spectrophotometers are often used to measure a color sample and compare that to a reference value. The difference should be displayed using any of the commonly available ΔE equations (ΔE^*_{ab}, ΔE^*_{94}, CIEDE2000, etc). In addition software should be able to provide an indication of pass/fail compared to a pre-determined target value.

Spectrophotometers will have a white calibration tile. In instances where this is a separate physical item, it should have a clearly labelled serial number. In many recent models the white calibration tile is integrated within the instrument, for example, in a lever that moves out of the way during measurement (X-Rite eXact) or within the charging stand (TECHKON SpectroDens). A number of instruments have a built-in white reference that does not get lost or soiled (X-Rite iSis2).

The measurement aperture is a consideration for applications such as signage where the large viewing distance allows for a very coarse halftone screen and very large halftone printed dots. In such instances a large measuring aperture is needed for the instrument, typically a switchable aperture of 2, 6, or 8 mm.

PANTONE® or other spot color libraries are often included within the instrument's firmware. Via measurement of a sample, the device can pick the nearest PANTONE equivalent and display the ΔE between the sample and its nearest identified PANTONE spot color.

Connectivity and onboard data storage are important considerations. Many devices will have cordless, battery operation and an on-board memory for storage of many measurements. The normal computer connection for instruments is USB. A number of devices support wireless WiFi or Bluetooth connectivity.

Practical considerations cause users to seek the maximum target size along with the smallest measurable patch size. The larger measurable sheet size allows more patches on a single sheet avoiding measurement variations when a target is spread across multiple sheets. The maximum size is limited by the width of the instrument, the X-Rite iSis2, for example, is A4/letter size, while the X-Rite iSis2XL model is A3/tabloid. If a device is able to discriminate between very small patches it allows more patches to fit on a sheet. This also allows for a small control bar to be discretely inserted on the press sheet allowing process control while not taking up valuable real estate.

Automatic chart-reading devices are popular in printer profiling because printer test charts have a large number of patches. The Konica-Minolta FD-9 is available with a feeder tray to automatically read a stack of test charts. In the table devices, the chart is printed and then placed on the table, usually with electrostatic assist. The spectrophotometer moves to every patch of the test chart, measuring and reporting the value for each color. Each software vendor needs to provide a printer profile chart in a format that can be read by their instrument.

Some devices, such as the X-Rite eXact and Barbieri SpectroPad2 have a touch screen interface that can make operation easier and quicker. Though not discussed here, spectrophotometers are also available for inline applications, such as within HP and Epson inkjet proofers and within digital presses for profiling and quality control.

It is not possible to declare an ideal spectrophotometer, all these instruments are excellent devices, but it is possible to determine the ideal spectrophotometer for you. A user should evaluate the features that are important to them and also consider the software that they want to use to ensure that the device is supported by third party software.

4.6.2 Ever Popular X-Rite i1Pro2

The X-Rite i1Pro2 is a widely used instrument that has become a household name in color management, Figure 4.12. The i1Pro2 (and earlier the i1Pro), is used in many different market segments, and in many different stand-alone and OEM configurations. The i1Pro2 instrument is a leading member of a X-Rite's extended family of i1 (Eye-One) hardware and software products. The i1Pro device started life with former GretagMacbeth company and became an X-Rite product in 2006. This spectrophotometer was called the i1Pro and had separate UV-included and UV-excluded models. It went through a number of revisions from Rev A to Rev D. A re-designed i1Pro2 (Rev E) has a very different look and uses a dual light source – tungsten and UV LED – to support M1 and M2 measurement modes within the same instrument.

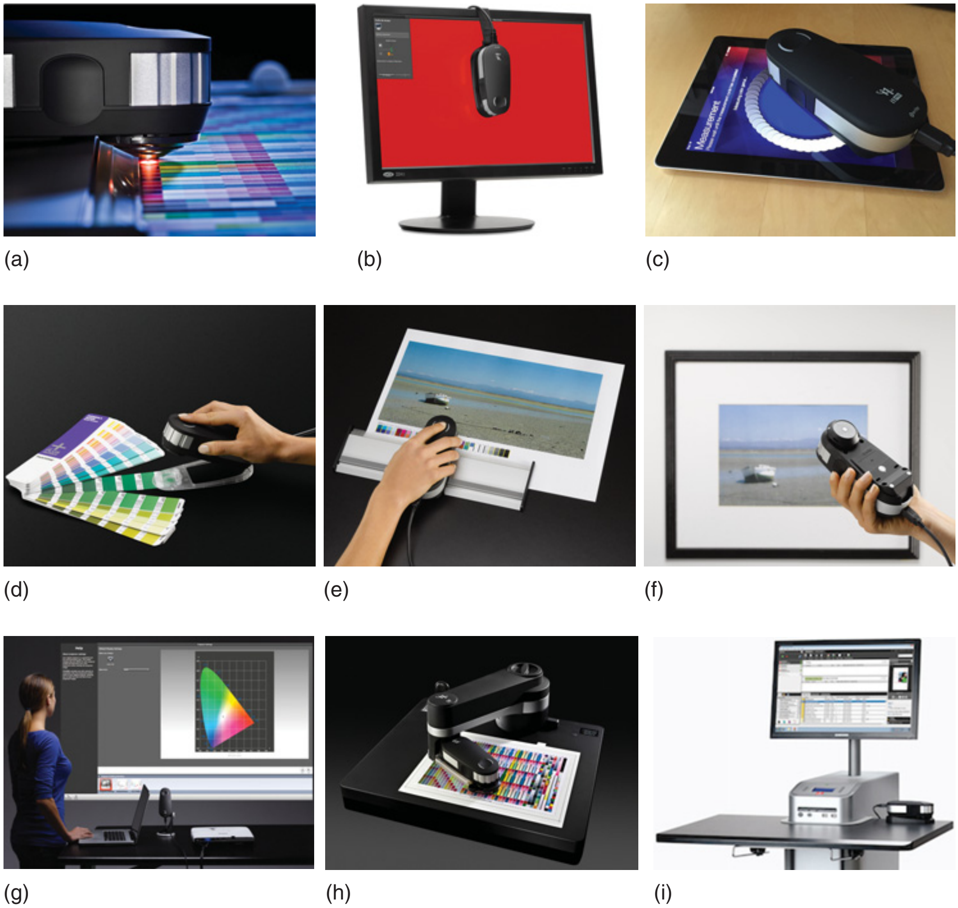


Figure 4.12 (a) The i1Pro2 has dual light source – tungsten and UV LED, allowing for M0, M1 and M2 measurement modes. (b) The i1Pro2 can measure a flat-panel display and (c) can be used with X-Rite ColorTrue to calibrate a tablet device. (d) Measurement in single patch mode is possible and (e) a sensor-aligned ruler is used to measure in strip mode. (f) Using the i1Pro2 to measure ambient light, or (g) with attachment to make a projector profile. (h) The i1Pro2 being used with the i1iO table. *Source:* X-Rite. Reproduced with permission of X-Rite. (i) The i1Pro2 is an OEM device for digital press calibration by EFI, called ES-2000. *Source:* EFI. Reproduced with permission of EFI.

The i1Pro2 is a versatile instrument as shown in the following parts of Figure 4.12. (a) The device has two light sources. (b) The i1Pro2 can make monitor profiles for flat-panels, and (c) it can be used to calibrate tablet devices with X-Rite ColorTrue software. (d) When measuring printed patches there is a single patch mode, and (e) a user can slide the instrument over the patches by hand, the instrument is guided along by a calibrated ruler that is sensed by the instrument. (f) The i1Pro2 can be used with a diffuser cap to measure the spectral characteristics of the ambient light. (g) The i1Pro has an attachment that allows it to be used in the profiling of video projectors. (h) The i1Pro2 can be attached to a chart-reading table called the i1iO. (i) The i1Pro2 is used as the calibration instrument for digital presses, such as the EFI Fiery Command WorkStation where it is branded as ES-2000.

4.6.3 OBA and UV Fluorescence

UV fluorescence is an issue that is related to color measurement and is an issue that has troubled color management users for a long time. What is UV fluorescence? Fluorescence is the process where ultraviolet radiation (<400 nm) is absorbed and converted to visible light and emitted in the 400–500 nm “blue” wavelength region. Chemicals called optical brightening agents (OBA) are commonly included within the coating layer of many types of paper and media. When these papers are viewed under a source that contains ultraviolet radiation the UV energy is absorbed by the OBA chemicals and emitted in the 400–500 nm part of the spectrum, creating a boost in the sample’s visible spectrum, Figure 4.13. This is a desirable effect as the fluorescence makes the media appear bluer and brighter, thus counteracting the yellow hue naturally found in wood fibre paper. The amount of “boost” in the blue wavelength region is related to the amount of UV energy in the illuminant and the amount of OBAs in the paper. In Figure 4.13 we see that an OBA-rich sample exhibits very different spectral response when the sample is measured with and without UV wavelengths in the measuring instrument light source.

One challenge with instrumentation has been that, when dealing with samples containing OBAs, there is often a difference in reported measurements between different

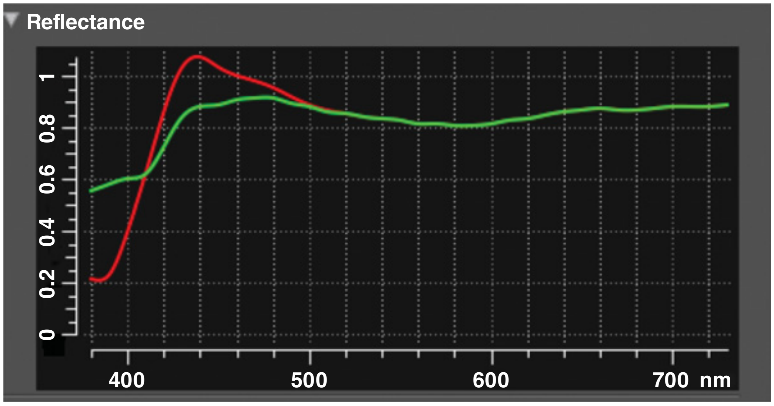


Figure 4.13 A paper with optical brighteners was measured with a spectrophotometer in UV-included (red line) and UV-excluded (green line) modes. UV-fluorescence causes the spike in the blue part of the spectrum, making the paper appear bluer and brighter.

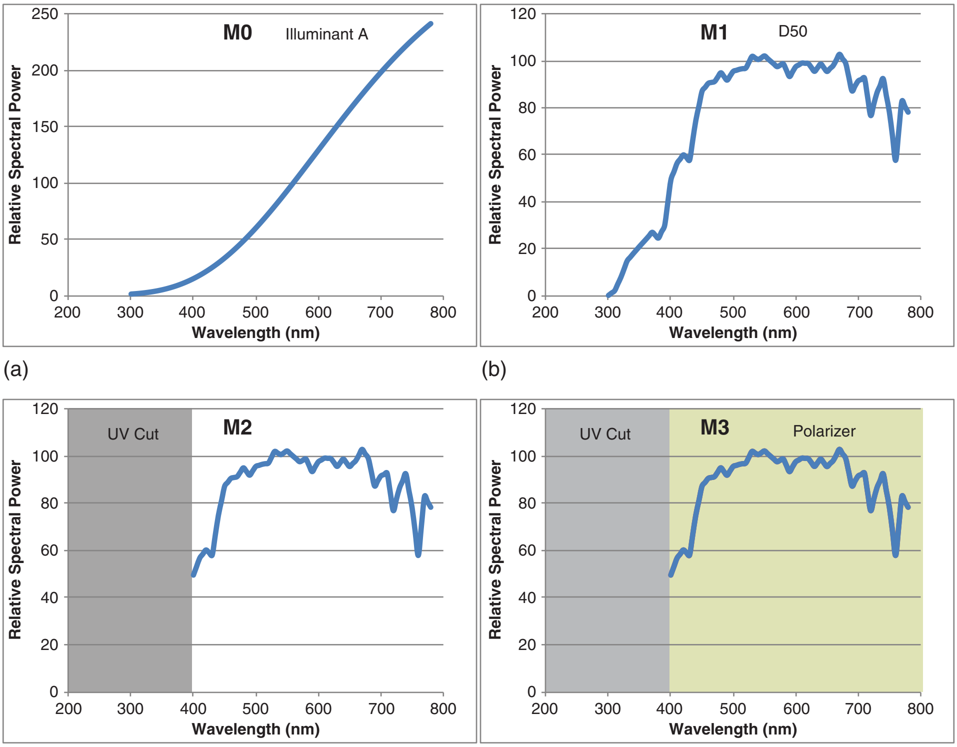
instruments. One reason that this problem occurs is that the UV component in the measuring instrument light source was not clearly specified, so different instruments can give different readings for the same sample.

When the UV component differs between instruments each measuring instrument will create a different amount of emission in the 400–500 nm wavelengths, which is computed into different L*a*b* values for the same sample. So two different instruments may read the same sample and report different values.

4.6.4 M0, M1, M2, M3 Measurement Modes

The challenge with instrumentation has been that there is often a difference in reported measurements between different instruments. A contributor to these differences was that the ultraviolet (UV) component of the illuminant in a measuring instrument could be different, which caused different instruments to give different readings for the same sample.

An international standard – ISO 13655 – now defines four measurement modes – M0, M1, M2 and M3, which clearly defines the UV component in measuring instruments, Figure 4.14. ISO 13655 was originally published in 1996 and revised in 2009.



(a) (b)

(c) (d)

Figure 4.14 ISO 13655 defines four new spectrophotometer measurement modes – M0, M1, M2, M3 – as described in the text.

The new version is called *ISO 13655:2009 – Graphic technology – Spectral measurement and colorimetric computation for graphic arts images*. The M0–M3 measurement modes were specified in 2009, but instrumentation, reference data and implementation in color management processes did not become mainstream until many years later. All manufacturers have been busy updating or releasing new instruments that meet this revised standard. The instrument modes defined in ISO 13655, are:

- M0 – legacy mode (any illumination source, tungsten lamp commonly assumed)
- M1 – D50, UV-included mode (this is the current recommended mode for color management)
- M2 – UV-excluded mode (removes all UV light from the measurement system, below 400 nm)
- M3 – polarizing mode (e.g. for measurement of wet offset press sheets or metallic inks).

M0 is known as the “legacy mode” and represents the majority of measuring instruments used in the field today. Prior to LED-based devices, the tungsten bulb-based device was the primary type of device on the market. It should be noted that, in this mode, the UV component can be very weak as seen by very low energy in the 300–400 nm range, Figure 4.14a. M0 legacy instruments may have unfiltered incandescent lamps but many will have filtered lamps that balance the spectral radiance within the instrument optics. As the lamps are low in short-wave radiation and the sensors are low in short-wave sensitivity, the filters reduce the flux at the longer wavelengths relative to the shorter wavelengths so that the optical gains can be nearly constant and the photometer can avoid having to auto-range to maintain a minimal signal-to-noise ratio.

An M0 instrument can safely be used for process control applications where it is adequate to make repeatable measurements, it can be used in situations where it is not necessary to know the “absolute” measurement value and there is no exchange of information or correlation with other measurement scenarios. The results from an M0 instrument, which has an unknown illuminant, cannot be considered interchangeable with another instrument of a different model in the presence of OBA’s. *Therefore it could be said that an M0 instrument is very repeatable but not necessarily accurate.* When instruments meeting M1 are not available and relative data is sufficient for process control or simple monitoring applications, an M0 instrument of like manufacturer and model provides a viable alternative. In general the M0 mode exists as a “catch-all” mode that allows for legacy devices to have a place within the new ISO standard, otherwise a large number of devices in the market place would be “out of spec.”

M1 is known as the “D50 mode” or “UV-included mode.” The light source in the instrument must create the effect of CIE Illuminant, D50. A major difference (and improvement) over earlier specifications is that in this mode the spectral power of the illuminant should approximate D50, thus the relative amount of UV and visible wavelengths is now specified, Figure 4.14b.

The clarification for spectral power in measuring instruments, ISO 13655, is accompanied by a similar clarification in the standard for viewing booths, *ISO 3664:2009 – Graphic technology and photography – Viewing conditions*. Via standards ISO 13655 and 3664, the amount of UV illumination is clarified, in both the measuring instrument and the viewing booth. *By implementing these two ISO standards, for the first time the instrument reported values are in agreement with what is observed visually in a viewing booth.*

D50 is the basis for the Profile Connection Space in the ICC architecture. D50 (M1) mode is available within the new generation of color measurement instruments. D50 is one of the standard viewing booth modes. The M1 measurement mode has been accepted worldwide in all areas of color measurement and management. Every device featured in Figure 4.9 is able to offer the M1 measurement mode. Some device names have been changed to indicate their compliance with the new standard, e.g. the X-Rite i1Pro has become the i1Pro2, and the X-Rite iSis and become the iSis2. *All of which make M1 the most desirable mode for measuring and managing color today.*

ISO 13655 allows for two methods to achieve conformance to the M1 (D50) illumination condition. The two methods are referred to as M1 – Method 1 and M1 – Method 2. If a device uses M1 – Method 1 they undertake to create a D50 response using physical, customized sources or imaging apparatus, as employed in the X-Rite eXact. In the case of M1 – Method 2 a system elicits a response as if illuminated by D50. Method 2 is used in the Konica Minolta instrument family. A crude generalization would be to say that Method 1 creates a "physical D50 response," while Method 2 is a "mathematical D50 response." Due to this difference, Method 1 devices can be used when either luminescent colorants or optical brighteners are of concern. Method 2 devices aim to correct for the effects of fluorescence of optical brighteners in the substrate only and not in the inks.

M2 is defined as a "UV-cut" mode. ISO 13655 states that "*to exclude variations in measurement results between instruments due to fluorescence of optical brightening agents... the measurement source shall only contain substantial radiation power in the wavelength range above 400 nm*." M2 is thus a UV-cut mode, filtering out any UV component in the instrument's light source, Figure 4.14c. How is this mode used in practice? There will be times when a customer will request a print to be measured using M2 because the lighting used to display the job is expected to be free of UV content. A museum is an example of one of the major places that may use UV-free lighting in order to preserve the exhibits on display. There may be other color management instances that require removing UV light from the measurement system. With ISO 13655, there is now a specific definition for "UV-cut" and the wavelength at which it occurs, Figure 4.14c. Note that the rest of the illuminant spectral power distribution for M2 is not specified, but it does not have to be as a measuring instrument in this range can simply compute the percentage of light incident and reflected from the sample.

It is useful to note that in the absence of optical brightening agents, M1 and M2 measurements are expected to be similar. Used in reverse, a test to determine if a media contains OBAs is to measure in both M1 and M2 modes and observe if there is any difference. If there is no difference then the material is OBA-free, as we often see in some proofing papers.

M3 is a mode that employs a polarizing filter. Polarizers are by their nature UV-cut filters. In the M3 mode, the amount of UV-cut consists of UV-cut up until 400 nm and a polarizing effect applied to the remaining wavelengths, Figure 4.14d. As above, the illuminant spectral power distribution from 400–700 nm for M3 is not specified. The main use of M3 is to limit or completely remove surface reflections. In the offset printing industry, one of the main concerns is that the press sheets come off the press wet and as they dry, the density of the ink drops. The M3 mode can aid printers in cutting the surface gloss from wet inks, as this may give a better prediction of the final expected dry density. The M3 mode has also been shown to be useful in measurement of metallic printing inks.

Because of the polarizing filter, the measured density value using M3 may be different to the density achieved from the other modes. In fact each mode (M0-M1-M2-M3) can produce a very different response and thus any computed metrics ($L^*a^*b^*$, Yxy, density) can be different. In order to report measurement data in an unambiguous way, it is suggested that all parameters are noted – including M0-M1-M2-M3 measurement mode, white or black backing, device make and model, etc.

4.7 Smartphone and Other Low-cost Systems

There is a range of new generation, low-cost instruments, that use an iPhone or Android device to report the $L^*a^*b^*$ of a sample. Some systems can incorporate a calibration card and can use the smartphone's camera and via an app use the phone's processing power. Another approach is to have a small physical sensor and provide a readout and communication via a smartphone app. A number of commercial and OEM systems are shown, Figure 4.15.

There are many applications for these low-cost devices in beauty and cosmetic applications, on-location for soil or water measurement, in an abattoir for evaluation of the color of meat, and in paint stores. The app interface can be personalized for OEM customers, and, internally, a matrix or other correction can be applied in order to tweak the color response of the system to particular colors to suit the intended application.

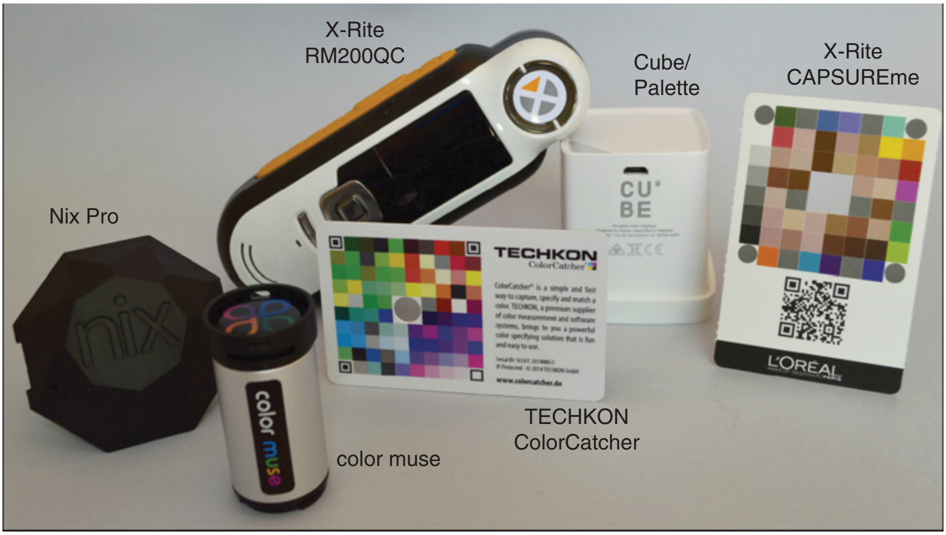
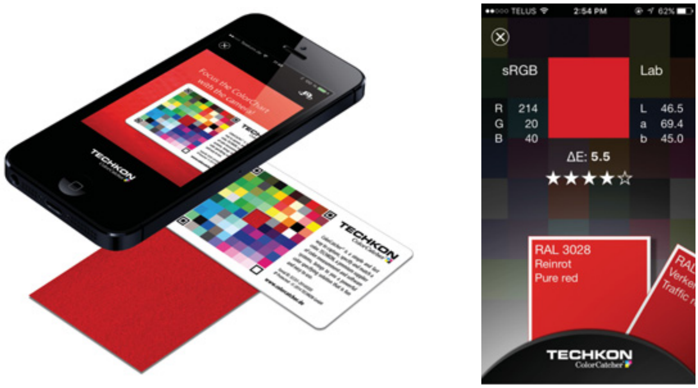


Figure 4.15 There are a number of low cost systems that can measure the $L^*a^*b^*$ value of a color sample. In independent testing, many of the devices shown here have an impressive accuracy of 1-2 ΔE when compared to a conventional spectrophotometer. *Source:* Courtesy of Sasha Blay.



sRGB
R 214
G 20
B 40

Lab
L 46.5
a 69.4
b 45.0

ΔE: 5.5
★★★★☆

RAL 3028
Reinrot
Pure red

(a)

(b)

Figure 4.16 (a) The TECHKON ColorCatcher card is placed over a red sample. (b) The ColorCatcher iPhone app displays sRGB, L*a*b* and the nearest spot color using the European RAL system. *Source:* TECHKON GmbH. Reproduced with permission of TECHKON GmbH.

As an example consider the TECHKON ColorCatcher technology that generates color data using different versions of the Apple iPhone and iPad, Figure 4.16. The ColorCatcher card is placed over the sample which shows through a cut-out window, Figure 4.16a, and the results are displayed in the ColorCatcher app, Figure 4.16b. The captured image is processed using the color engine embedded in the ColorCatcher App to display RGB and L*a*b* values. In addition the nearest spot color using the European RAL CLASSIC spot color system is determined and displayed in the lower part of the screen, Figure 4.16b.

A question users may ask is, how accurate are these devices compared to a conventional spectrophotometer? In a simple test, a Macbeth 24 patch chart was measured with a conventional TECHKON SpectroDens spectrophotometer and then the same patches were measured again using the systems shown in Figure 4.15. Figure 4.17 shows the ΔE calculated between each device shown in the figure and a SpectroDens spectrophotometer. As a sanity check, the 24 patches of the ColorChecker were measured again with the same TECHKON SpectroDens instrument and that data is shown in the first column of Figure 4.17. In this graph, a lower ΔE, i.e. a shorter bar chart is better.

In general, a user may readily accept up to 3.0 average ΔE variation, between a low-cost device and a conventional spectrophotometer. These results indicate that low-cost instruments can offer very accurate color measurements.

4.8 Inter-instrument and Inter-model Agreement

Ideally, two instruments of the same design should measure a sample exactly the same. However, in practice, there is often a difference in reported measurements between different instruments. The difference is usually small between different units of the same model, and can be larger between different models from the same manufacturer or models from different manufacturers. The term – *inter-instrument agreement* – is used to describe the difference in measurement between two units of the same model, while

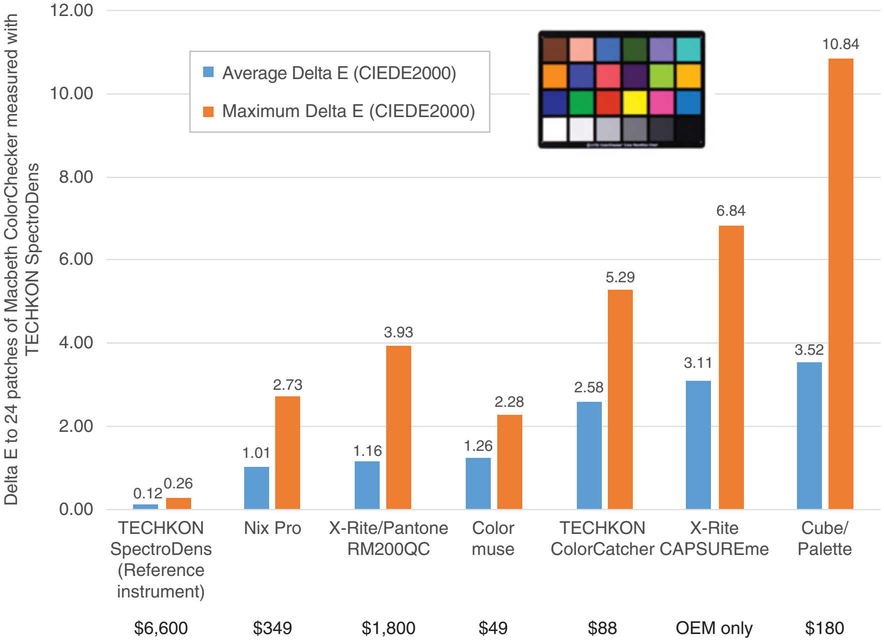


Figure 4.17 The low-cost systems shown in Figure 4.15 were tested in their ability to measure 24 patches of a Macbeth ColorChecker. The reference instrument was a TECHKON SpectroDens commercial spectrophotometer. In this graph a shorter bar, lower ΔE, is better.

inter-model agreement is used to compare different models from one manufacturer or two different models from different manufacturers.

Consider *inter-instrument agreement*. If your workplace has a number of devices, how much can the measurements vary if you use different devices to measure the same job?

Two spectrophotometers of the exact same make and model will typically measure a sample to within 0.25 ΔE^*_{ab} of each other. (Inter-instrument agreement will usually be better than inter-model agreement.)

Poor *inter-model agreement* causes a number of issues when different devices are used to manage color in production scenarios. Inter-model differences have ramifications as we get into measuring very small color differences that approach instrumental limits. The printer may, for example, measure and pass a print job as acceptable and within tolerance, while the customer using a different instrument may determine that the colors are out of tolerance and reject the shipment. Instrument suppliers should, but do not publicly quote values for inter-model agreement.

4.9 Instrument Repeatability vs. Accuracy

When considering measuring instruments, it is useful to consider the causes for disparity between instruments in terms of *repeatability* and *accuracy*. Repeatability refers to how spread out the measurements are when an instrument is used to successively

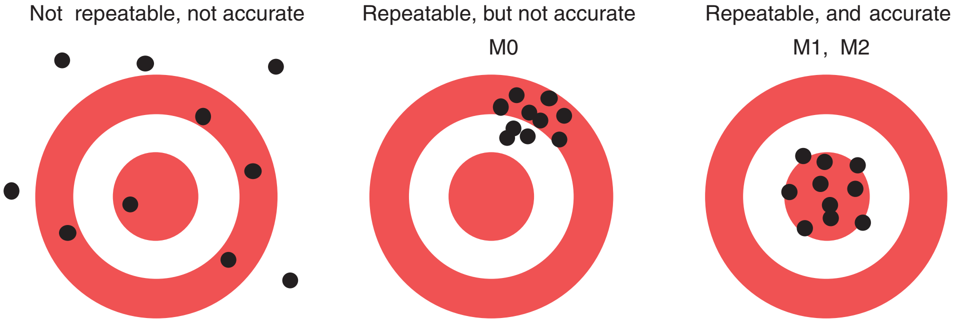


Figure 4.18 Systems can be neither repeatable nor accurate (left), M0 systems may be repeatable, but not accurate (centre). Instruments, such as M1 and M2 mode devices, are best, because they are both repeatable and accurate (right).

measure the same sample, Figure 4.18. As the grouping of the cloud of repeat measurements gets smaller, repeatability improves. It is important to have a repeatable process, only when a process or instrument is repeatable can we begin to control the process. If an instrument or process is repeatable, then there is only the less onerous task of moving that response towards the required target value to increase its accuracy.

Manufacturers will normally publish how repeatable their instrument is. For a typical reflection spectrophotometer, subsequent measurements can differ by an average of 0.05 ΔE^*_{ab}.

Accuracy refers to the distance of the measurement values from the target or aim value. Accuracy describes the distance between the measurements taken by the color measurement instrument and the "real" value that measurement should be if measured with a laboratory reference device. We may consider the M0 generation of instruments repeatable, but not necessarily accurate.

4.10 Instrument Calibration

A general concept applicable to all instrument types is calibration. Before you can use any measuring instrument, it must be properly set up and calibrated. If you are relying on instruments in important operations, it is vital to know that the instrument is operating correctly. There are different levels of instrument calibration. User-level *calibration* should be done every time the instrument is used. *Recertification* involves sending the instrument back to the manufacturer every 12–18 months for them to check the device and reissue a certificate. *Traceability* is the process in which an instrument is referenced to a national or international standard. Let's look at each of these in turn.

The calibration process resets the instrument so that the readings are accurate and repeatable. Take, for example, the analogy of bathroom scales. If the dial is not set to zero before you try to weigh yourself, your correct weight will not be shown. In the same way, all instruments must be set to zero before measurements are taken, and this is achieved by calibration.

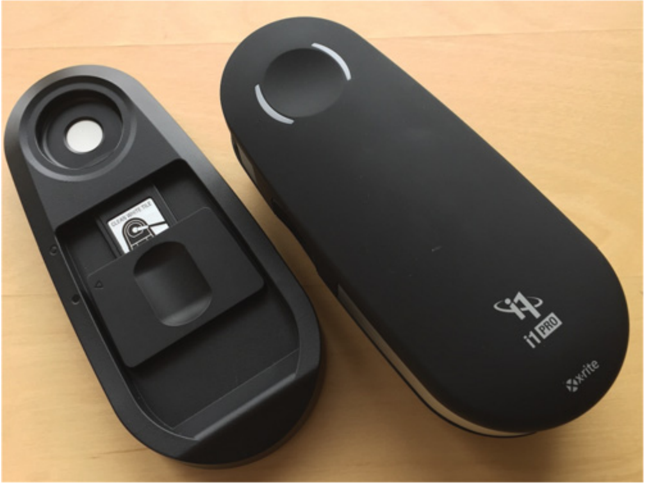


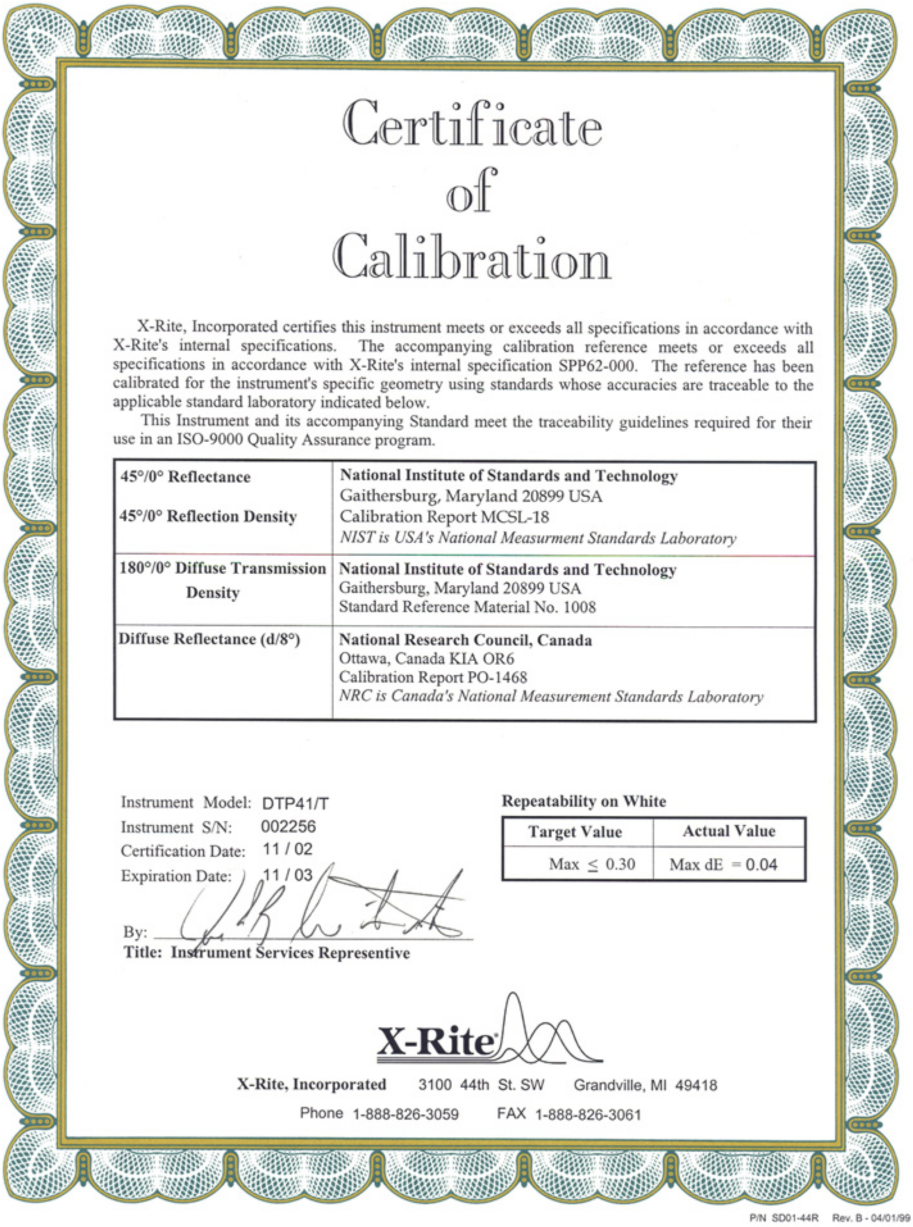
Figure 4.19 All instruments should be calibrated prior to use. The X-Rite i1Pro2 comes with a base that incorporates a white tile with a slider cover.

Spectrophotometers will have a white calibration tile. In some newer models the white calibration tile is accessible via a sliding cover, Figure 4.19. Calibration needs to be performed on a regular basis, before and even between measurements.

About every year, an instrument should be sent back to the manufacturer to be re-certified. When an instrument is manufactured, it is issued with a certificate or statement of calibration that confirms the device is working as intended. One such certificate is shown in Figure 4.20. During normal use an instrument can get knocked and its components misaligned. It is necessary for the instrument to be checked and a certificate reissued to state that the instrument is still in working order and is producing reliable results. Any legally binding discussion or litigious case would need to be contested with a certified instrument.

The instrument manufacturer carries out another level of instrument verification behind the scenes. To provide a reliable framework, all instrument data is derived ultimately from a standardized source. National laboratories have sophisticated equipment for measuring and establishing precise light output and colorimetric measurements. A vendor will obtain calibrated tiles from a national laboratory. The generic term for such tiles is Certified Reference Materials (CRM), an example of a popular CRM material is BCRA tiles.

These tiles will be used as transfer calibrations and will be brought back to the factory where they may be copied to create a local "master." The local master will then be used to calibrate and control the instruments being produced in the production line. Thus, the data from any instrument is ultimately *traceable*, via a series of steps, to a national or international standard. The standard agency may be the National Institute of Standards and Technology in Gaithersburg, Maryland, or the National Research Council Canada in Ottawa, and in the UK it may be the National Physical Laboratories in Teddington, just outside London.



Certificate of Calibration

X-Rite, Incorporated certifies this instrument meets or exceeds all specifications in accordance with X-Rite's internal specifications. The accompanying calibration reference meets or exceeds all specifications in accordance with X-Rite's internal specification SPP62-000. The reference has been calibrated for the instrument's specific geometry using standards whose accuracies are traceable to the applicable standard laboratory indicated below.

This Instrument and its accompanying Standard meet the traceability guidelines required for their use in an ISO-9000 Quality Assurance program.

45°/0° Reflectance **45°/0° Reflection Density**	**National Institute of Standards and Technology** Gaithersburg, Maryland 20899 USA Calibration Report MCSL-18 *NIST is USA's National Measurment Standards Laboratory*
180°/0° Diffuse Transmission Density	**National Institute of Standards and Technology** Gaithersburg, Maryland 20899 USA Standard Reference Material No. 1008
Diffuse Reflectance (d/8°)	**National Research Council, Canada** Ottawa, Canada KIA OR6 Calibration Report PO-1468 *NRC is Canada's National Measurement Standards Laboratory*

Instrument Model: DTP41/T
Instrument S/N: 002256
Certification Date: 11 / 02
Expiration Date: 11 / 03

By:
Title: Instrument Services Representive

Repeatability on White

Target Value	Actual Value
Max ≤ 0.30	Max dE = 0.04

X-Rite

X-Rite, Incorporated 3100 44th St. SW Grandville, MI 49418
Phone 1-888-826-3059 FAX 1-888-826-3061

P/N SD01-44R Rev. B - 04/01/99

Figure 4.20 Every instrument must be accompanied by a certificate that contains many details including traceability to a national standard.

4.11 Summary

Color management relies on instrumentation, and in today's marketplace there are a wide range of devices to choose from.

In this chapter we saw that when choosing an instrument for color management we must consider what the device measures. We saw that a densitometer has limited use in color management and that a colorimeter or spectrophotometer is the minimum needed to measure and monitor color in a meaningful manner.

In order to deal with the phasing out of CRT display technologies and the near complete adoption of flat-panel display systems, there are a number of technology developments in the colorimeter market for monitor calibration and profiling, illustrated in this chapter by colorimeter solutions from Datacolor and X-Rite.

There is a growing trend to use spectral data in many applications in addition to the traditional measures of XYZ and L*a*b*. As spectrophotometers become commonplace, and the memory needed to store spectral data is not an issue, more and more applications are using spectral data to offer many beneficial features, such as the ability to change the reference illuminant at a later stage.

The addition of OBAs in substrates introduces many challenges for accurate color measurement because different instruments can report different measurements of the same sample. ISO 13655 has helped clarify the UV composition in the instrument configuration and has defined four measurement modes – M0, M1, M2, M3. All manufacturers have now released a new generation of M1-compliant instruments that meet this revised standard. Users should always use the M1 mode and know how to find it in software and hardware.

When we rely so heavily on instruments to manage color, it is important to care for our instruments as they are precision devices. Calibration and other steps to ensure measurement accuracy are necessary.

Color management today is entirely measurement based and uses the instruments and processes described in this chapter.

5

Inside Profiles

Objectives

- Describe the ICC Specifications and ICC ISO Standards.
- Explain ICC profile header and tags.
- Describe everyday issues such as the internal profile name and cube nodes.
- Consider v2 and v4 profile types.
- Introduce v5 iccMAX profiles and architecture.
- Show, using an example, how a lookup table works.

5.1 Introduction

This chapter looks at ICC profiles and provides a technical explanation to their internal structure and operations. While this level of detail may not be needed to use a color-managed workflow such knowledge helps understand how color management works. By way of an analogy, you can use your car and get from point A to point B without knowing the intricacies of engine mechanics. However, if your car breaks down, or is not performing as required, you have a problem. In car mechanics or ICC color management, you can make informed decisions if you have an appreciation of the underlying principles and components of the process.

An ICC profile is a data file describing the color characteristics of an imaging device. ICC profiles can be made for scanners, digital cameras, monitors, or printers. There are also “non-device” profiles such as color space profiles for special situations.

The structure of a profile is strictly regulated so that a wide range of software, from many different vendors, and at different parts of the workflow (e.g. image editing, preview, processing, internet preparation, and printing) can use a profile. It doesn’t matter which company made the profile, which program is using it, or which profile inspector is being used to view its contents – everybody can use and view and edit a profile because of the strictly regulated and adhered to, ICC file format specification.

Profiles consist of two parts: a header and tags. The header contains information about the device type, CMM, etc. The tags form the body of the profile and contain the working part of the profile including various lookup tables. This chapter describes the header and

Understanding Color Management, Second Edition. Abhay Sharma.
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tags found in scanner, monitor, and printer profiles. This chapter also describes some of the changes that have occurred as profiles evolve from v2 to v4, and to the new iccMAX v5 profiles.

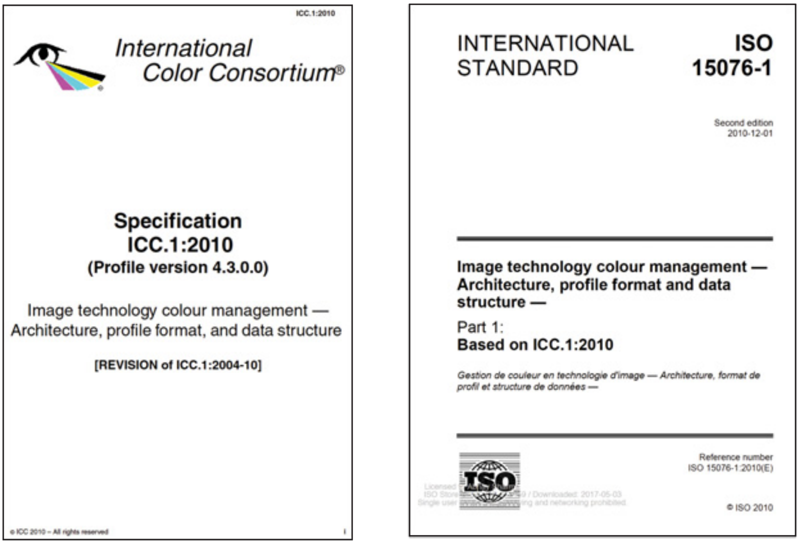
Profile inspectors are special software tools that can be used to view the contents of a profile. In this chapter we use two free utilities – ColorSync Utility (macOS) and ICC Profile Inspector (Windows) to view the contents of ICC profiles. An excellent, commercial product, Chromix ColorThinkPro is also used in some examples.

Finally, an explanation is provided for how a lookup table works. Lookup tables are fundamental to color management and thus a practical example is presented to clearly demonstrate the operation of a lookup table.

5.2 ICC Profile Specification

The format of profiles is specified by the International Color Consortium (ICC) via a *specification* called Specification ICC.1, Figure 5.1. The specification is also submitted via appropriate national and international committees to be published as an international *standard*, ISO 15076. The ICC specification and corresponding ISO standard have identical content, Table 5.1.

The ICC Specification is available free from the ICC web site (www.color.org), while the ISO Standard can be purchased and downloaded from the ISO web site (www.iso.org).



ICC.1:2010

International
Color Consortium®

Specification
ICC.1:2010
(Profile version 4.3.0.0)

Image technology colour management —
Architecture, profile format, and data structure

[REVISION of ICC.1:2004-10]

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(a)

INTERNATIONAL
STANDARD

ISO
15076-1

Second edition
2010-12-01

Image technology colour management —
Architecture, profile format and data
structure —

Part 1:
Based on ICC.1:2010

Gestion de couleur en technologie d'image — Architecture, format de
profil et structure de données —

Reference number
ISO 15076-1:2010(E)

© ISO 2010

(b)

Figure 5.1 The structure and internal format of profiles is specified by the International Color Consortium (ICC) via (a) a technical document called the Specification ICC.1, or (b) an equivalent ISO standard – ISO 15076.

Table 5.1 Profile version numbers correspond with the ICC specification and an ISO standard.

Profile Version	Year	ICC Specification	ISO Standard
v2	2001	Specification ICC.1:2001-04	ISO 15076 (2005)
v4	2010	Specification ICC.1:2010-12	ISO 15076 (2010)
v5	2016	Specification ICC.2:2016-07	ISO 20677

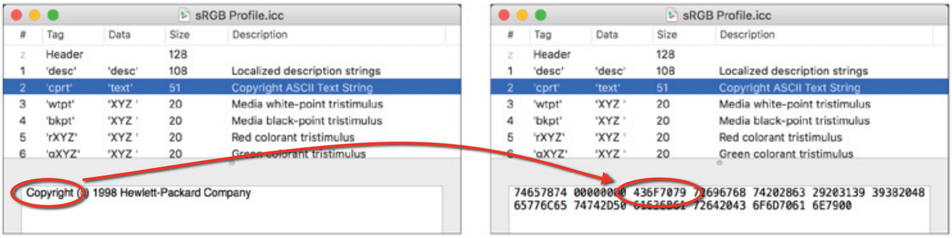
5.3 Hexadecimal Profile Encoding

ICC profile content is binary data, displayed using hexadecimal notation. We provide a brief computer science review of binary, decimal, and hexadecimal systems. The number systems are summarized as follows.

- *Binary* – uses just two digits – 0, 1 – on or off
- *Decimal* – our normal counting system, uses ten digits – 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
- *Hexadecimal* – uses sixteen digits – 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

Computer data is most efficiently stored as 0 or 1, binary bits. The hexadecimal numbering system is a multiple of 2 ($2^4 = 16$) and is therefore a convenient encoding system for computer data. The whole of an ICC profile is encoded in hexadecimal notation. Data within a profile is stored as a 4-byte hexadecimal number, Figure 5.2. Take for example the letters “C-o-p-y”, these are stored as hexadecimal “43-6F-70-79.” The hexadecimal encoding is visible by a hidden keyboard shortcut, to see the hexadecimal encoding, in ColorSync Utility, hold down the alt/option key before clicking on a tag element. Here we have translated one element from an ICC profile, keen readers can look up each hexadecimal number and find the ASCII translation for the remaining content.

The hexadecimal encoding is convenient for computer systems but it is not easy for a user to open and examine a profile’s content. While profile inspector software and programmer level tools such as Matlab can open and parse the contents of an ICC profile, in general, the internal profile structure remains largely inaccessible to the average user. If ICC profile encoding were developed today, a more accessible format such as XML



#	Tag	Data	Size	Description
z	Header		128	
1	'desc'	'desc'	108	Localized description strings
2	'cprt'	'text'	51	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'rXYZ'	'XYZ '	20	Red colorant tristimulus
6	'gXYZ'	'XYZ '	20	Green colorant tristimulus

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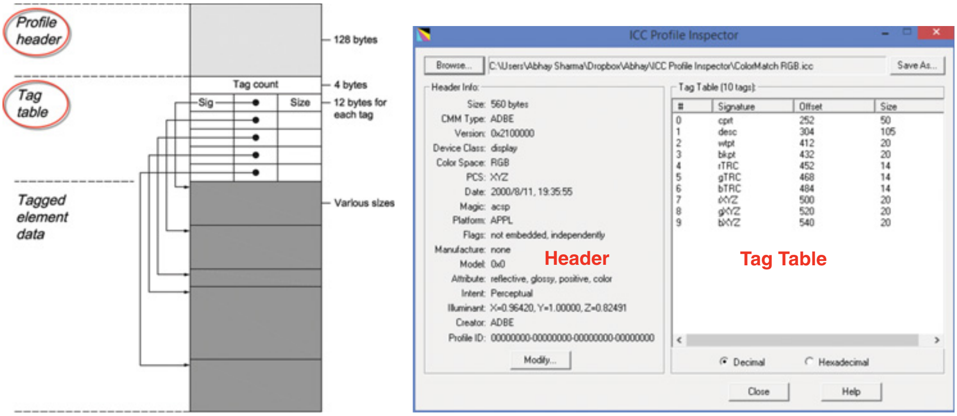
#	Tag	Data	Size	Description
z	Header		128	
1	'desc'	'desc'	108	Localized description strings
2	'cprt'	'text'	51	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'rXYZ'	'XYZ '	20	Red colorant tristimulus
6	'gXYZ'	'XYZ '	20	Green colorant tristimulus

```
74657874 00000000 436F7079 72696768 74202863 29203139 39382048
65776C65 74742D50 61636B61 72642043 6F6D7061 6E7900
```

Figure 5.2 ColorSync Utility displays a profile’s content in human readable form, to see the underlying hexadecimal encoding, hold down the alt/option key before clicking on the tag.



C:\Users\Abhay Sharma\Dropbox\Abhay\ICC Profile Inspector\ColorMatch RGB.icc

Header Info:

Size: 560 bytes
CMM Type: ADBE
Version: 0x2100000
Device Class: display
Color Space: RGB
PCS: XYZ
Date: 2000/8/11, 19:35:55
Magic: acsp
Platform: APPL
Flags: not embedded, independently
Manufacture: none
Model: 0x0
Attribute: reflective, glossy, positive, color
Intent: Perceptual
Illuminant: X=0.96420, Y=1.00000, Z=0.82491
Creator: ADBE
Profile ID: 00000000-00000000-00000000-00000000

Tag Table (10 tags):

#	Signature	Offset	Size
0	cprt	252	50
1	desc	304	105
2	wtpt	412	20
3	bkpt	432	20
4	rTRC	452	14
5	gTRC	468	14
6	bTRC	484	14
7	rXYZ	500	20
8	gXYZ	520	20
9	bXYZ	540	20

● Decimal ○ Hexadecimal

(a) (b)

Figure 5.3 (a) The ICC Specification defines a profile header with fixed entries, and a tag table with varying entries. (b) ICC Profile Inspector shows the header and tag table for a profile.

may be used to encode profile data. XML is used in many color technology areas such as the Windows Color System (WCS), iccMAX (v5 ICC profile architecture) and CxF (spot color data files).

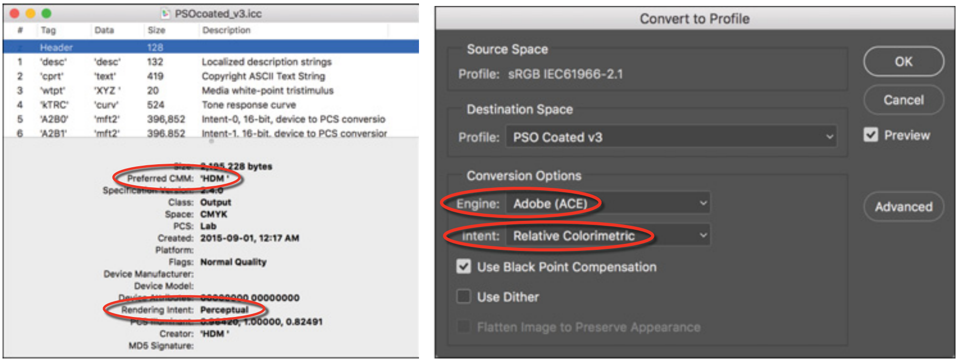
5.4 Structure of an ICC Profile

Consider the structure of an ICC profile, Figure 5.3a. An ICC profile contains a header followed by a tag table. The header is a standardized part of a profile and contains a fixed number of items. The tag table contains the tag signature followed by the offset or location of the tag's contents, and finally the size of the tag is provided.

The ICC specifies a list of required tags for each type of profile. Thus, monitor profiles must have a tone reproduction curve tag, whereas printer profiles require appropriate lookup tables. Without the required tags the profiles are not valid profiles. As all parties adhere to this format profile-making software can create profiles and applications can safely import and use profiles.

5.5 Profile Header

The header is a standardized part of a profile and is filled in by the program that creates the profile. The ICC recommends that all header fields are used so as to provide the most complete information about a device and how and when the profile was built. *As the header information is standardized and is available in all profiles, software applications can rely on it being there.* As long as the header is filled in correctly this provides a reliable way for programs to open and use ICC profiles without hanging or crashing the program. Let's look at some of the parts of the profile header and see how these fields are interpreted and used by software applications.



PSOcoated_v3.icc

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'desc'	132	Localized description strings
2	'cprt'	'text'	419	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'kTRC'	'curv'	524	Tone response curve
5	'A2B0'	'mft2'	396,852	Intent-0, 16-bit, device to PCS conversio
6	'A2B1'	'mft2'	396,852	Intent-1, 16-bit, device to PCS conversior

Size: 2,105,228 bytes
Preferred CMM: 'HDM '
Specification Version: 2.4.0
Class: Output
Space: CMYK
PCS: Lab
Created: 2015-09-01, 12:17 AM
Platform:
Flags: Normal Quality
Device Manufacturer:
Device Model:
Device Attributes: 00000000 00000000
Rendering Intent: Perceptual
PCS Illuminant: 0.96420, 1.00000, 0.82491
Creator: 'HDM '
MD5 Signature:

Convert to Profile

Source Space
Profile: sRGB IEC61966-2.1

Destination Space
Profile: PSO Coated v3

Conversion Options
Engine: Adobe (ACE)
Intent: Relative Colorimetric
☑ Use Black Point Compensation
☐ Use Dither
☐ Flatten Image to Preserve Appearance

(a) (b)

Figure 5.4 (a) The profile header contains fields for Preferred CMM, and Rendering Intent, which are probably not relevant as (b) software applications, such as Photoshop allow the user to override these settings during runtime.

5.5.1 Preferred CMM

One of the first fields in the header is the Preferred CMM, Figure 5.4a. The CMM is the color management module. The CMM is a color engine that does the color conversions on image data. When an image and profiles are sent to the CMM, the role of the CMM is to convert the image data from one color space to another using the information in the profiles. CMMs are available from various vendors, including Adobe, Agfa, Apple, Canon, EFI, Heidelberg, Kodak, Little CMS, Microsoft, etc.

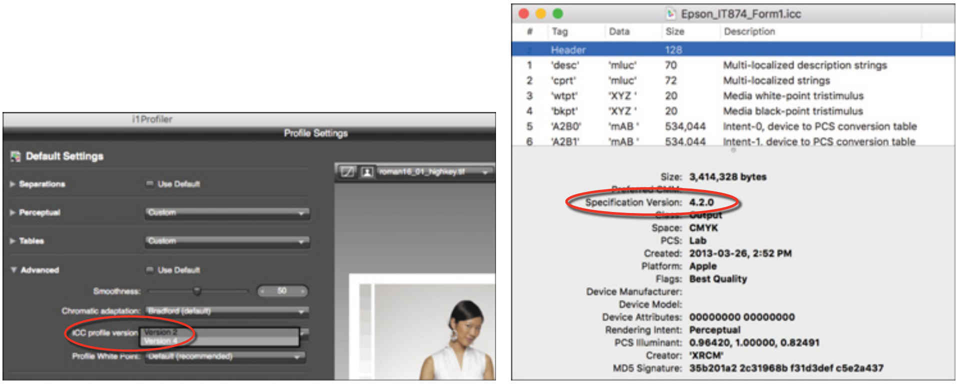
The CMM name within the profile must be a registered abbreviation. There is a list of CMM signatures registered with the ICC and available in an ICC registry at www.color.org. Figure 5.4a shows the preferred CMM, in this example it is “HDM”, which is the registered abbreviation for Heidelberg.

The CMM field in a profile header specifies the default CMM to be used, but in many instances software applications will allow a user to override the entry in the profile. Photoshop, for example, allows the user to select the CMM at run time, where in Figure 5.4b, the preferred CMM is being overwritten by the Adobe Color Engine (ACE) CMM.

The intention is that all CMMs behave in more or less the same way, but there may be some difference in the results obtained using different CMMs. Some users may wish to choose the same CMM on the macOS and Windows platforms to ensure that the results are identical between Mac and PC users. The Adobe Color Engine for example is available on both the Mac and Windows platforms.

5.5.2 Specification Version

The Specification Version field corresponds to the version number of the ICC specification, older profiles have version numbers of v2, and newer profiles should be v4 or v5. Profile-making software will often allow the user to create a v2 or v4 profile, Figure 5.5a. The chosen version is then encoded in the header as the Specification Version, Figure 5.5b.



Separations: Use Default
Perceptual: Custom
Tables: Custom
Advanced: Use Default
Smoothness: 50
Chromatic adaptation: Bradford (default)
ICC profile version: Version 2 / Version 4
Profile White Point: Default (recommended)

(a)

Epson_IT874_Form1.icc

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'mluc'	70	Multi-localized description strings
2	'cprt'	'mluc'	72	Multi-localized strings
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'A2B0'	'mAB '	534,044	Intent-0, device to PCS conversion table
6	'A2B1'	'mAB '	534.044	Intent-1, device to PCS conversion table

Size: 3,414,328 bytes
Preferred CMM:
Specification Version: 4.2.0
Class: Output
Space: CMYK
PCS: Lab
Created: 2013-03-26, 2:52 PM
Platform: Apple
Flags: Best Quality
Device Manufacturer:
Device Model:
Device Attributes: 00000000 00000000
Rendering Intent: Perceptual
PCS Illuminant: 0.96420, 1.00000, 0.82491
Creator: 'XRCM'
MD5 Signature: 35b201a2 2c31968b f31d3def c5e2a437

(b)

Figure 5.5 (a) During profile creation, X-Rite i1Profiler allows the user to make a v2 or v4 profile. (b) The version chosen during profile creation is stored in the profile header.

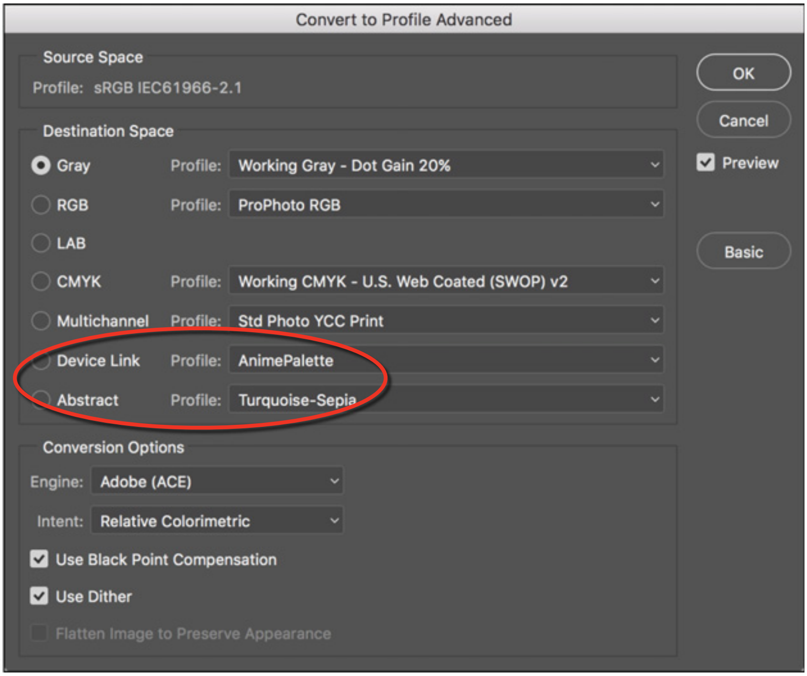
In general the version number is incremented when it is necessary that the color management module (CMM) be upgraded in order to correctly use a profile.

5.5.3 Profile Class

An important part of the profile header is the Class field. The Class tells us what type of profile we have, such as digital camera, monitor, printer, and so on. There are seven profile classes: input (scnr), display (mntr), output (prtr), device link (link), color space (spac), abstract (abst), and named color (nmcl), Table 5.2. The reason the Class entry is important is that it indicates what sorts of tags to expect in the tag table part of the profile; thus when opening a profile most software will look first at the Class field.

Table 5.2 Most ICC profiles are of type Basic Class, Additional Class profiles are used in special situations.

Profile Class	Signature	Hex encoding
	Basic Class	
Input device profile	scnr	73636E72h
Display device profile	mntr	6D6E7472h
Output device profile	prtr	70727472h
	Additional Class	
DeviceLink profile	link	6C696E6Bh
ColorSpace profile	spac	73706163h
Abstract profile	abst	61627374h
NamedColor profile	nmcl	6E6D636Ch



Convert to Profile Advanced

Source Space

Profile: sRGB IEC61966-2.1

Destination Space

● Gray Profile: Working Gray - Dot Gain 20%

○ RGB Profile: ProPhoto RGB

○ LAB

○ CMYK Profile: Working CMYK - U.S. Web Coated (SWOP) v2

○ Multichannel Profile: Std Photo YCC Print

○ Device Link Profile: AnimePalette

○ Abstract Profile: Turquoise-Sepia

Conversion Options

Engine: Adobe (ACE)

Intent: Relative Colorimetric

☑ Use Black Point Compensation

☑ Use Dither

☐ Flatten Image to Preserve Appearance

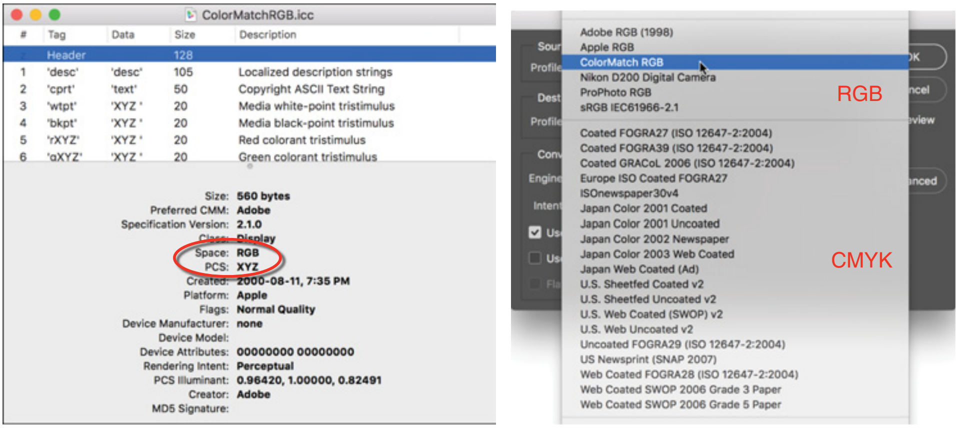
Figure 5.6 Device Link and Abstract profile types are now supported in Adobe Photoshop.

Input, display and *output* profiles are basic, standard profile types. *DeviceLink* profiles are profiles that allow for direct device-to-device conversions. A device link profile, for example, may be a CMYK-to-CMYK profile. Device link profiles are made from two profiles joined together. You can achieve the effect of a device link profile by processing an image sequentially through two profiles, or concatenating them together to form a single device link profile. A device link profile provides a convenient shortcut, so if you know you always want to use two devices (for example, an offset press and inkjet proofer, in a proofing scenario), you can combine the profiles which reduces the number of operations and removes the risk of user error. Photoshop, Figure 5.6, now supports device link profiles as do most RIPs, servers, and other color software systems.

Examples of *ColorSpace* profiles are "Generic L*a*b* Profile" and "Generic XYZ Profile." Color space profiles are used to convert image data into or out of a device-independent color space. The macOS has a number of color space profiles installed as part of the system architecture. *Abstract* profiles are used for special purposes – for example, to store image edits, as shown in the Photoshop dialog, Figure 5.6. *Named-Color* profiles are used to support color systems such as data for a PANTONE® library.

5.5.4 Data Color Space and PCS

Data Color *Space* refers to the device color space and *PCS* refers to the Profile Connection Space. These fields indicate which color spaces the profile can convert between, Figure 5.7. The Data Color Space will be either RGB or CMYK and the PCS will be either



ColorMatchRGB.icc

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'desc'	105	Localized description strings
2	'cprt'	'text'	50	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'rXYZ'	'XYZ '	20	Red colorant tristimulus
6	'gXYZ'	'XYZ '	20	Green colorant tristimulus

Size: 560 bytes
Preferred CMM: Adobe
Specification Version: 2.1.0
Class: Display
Space: RGB
PCS: XYZ
Created: 2000-08-11, 7:35 PM
Platform: Apple
Flags: Normal Quality
Device Manufacturer: none
Device Model:
Device Attributes: 00000000 00000000
Rendering Intent: Perceptual
PCS Illuminant: 0.96420, 1.00000, 0.82491
Creator: Adobe
MD5 Signature:

Adobe RGB (1998)
Apple RGB
ColorMatch RGB
Nikon D200 Digital Camera
ProPhoto RGB
sRGB IEC61966-2.1
RGB
Coated FOGRA27 (ISO 12647-2:2004)
Coated FOGRA39 (ISO 12647-2:2004)
Coated GRACoL 2006 (ISO 12647-2:2004)
Europe ISO Coated FOGRA27
ISOnewspaper30v4
Japan Color 2001 Coated
Japan Color 2001 Uncoated
Japan Color 2002 Newspaper
Japan Color 2003 Web Coated
Japan Web Coated (Ad)
U.S. Sheetfed Coated v2
U.S. Sheetfed Uncoated v2
U.S. Web Coated (SWOP) v2
U.S. Web Uncoated v2
Uncoated FOGRA29 (ISO 12647-2:2004)
US Newsprint (SNAP 2007)
Web Coated FOGRA28 (ISO 12647-2:2004)
Web Coated SWOP 2006 Grade 3 Paper
Web Coated SWOP 2006 Grade 5 Paper
CMYK

(a) (b)

Figure 5.7 Photoshop creates its menus from the information in the Data Color Space field of a profile header.

XYZ or L*a*b*. Monitor profiles tend to be characterized by a matrix transform and will therefore often use XYZ as the PCS, while lookup table-based printer profiles commonly use L*a*b*. A CMM can deal with, and easily convert between color spaces, so there is no restriction on mixing XYZ and L*a*b* profiles. Profiles generally have the ability to convert data in both directions; that is, from PCS to Data Color Space and vice versa. The direction used to process the data is determined automatically, depending on the order in which the profiles are presented to the CMM.

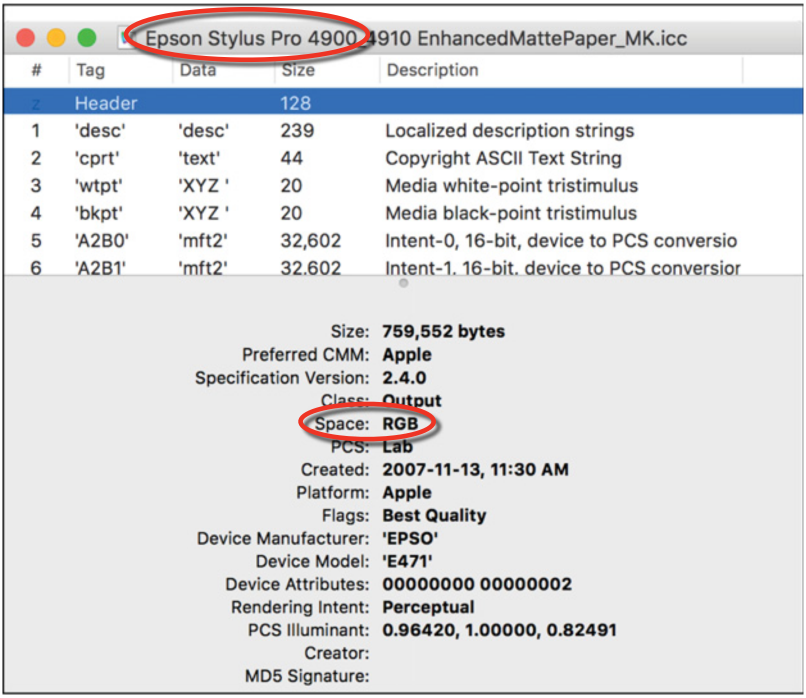
In the case of an output profile, the Data Color Space may be CMYK or n-color, where “n” can be up to 16. In expanded gamut printing it is common to see a Data Color Space field of “6-Color.” Note that a Data Color Space of “CMYK” and “4-Color” is not the same thing, both are 4-channel profiles, but the CMYK assumes the colorants are C-M-Y-K, while “4-Color” does not.

There are some practical uses for the Data Color Space field. Software programs, such as Photoshop can use data within the profile header to order and display profiles in a menu list, Figure 5.7. Photoshop uses the information from the Data Color Space field to list profiles according to their color space (e.g. RGB, CMYK, or Grayscale).

The Data Color Space field in the profile header can be useful for other purposes, for example, color management systems can treat inkjet printers as RGB or CMYK devices. Figure 5.8 shows an RGB profile for an Epson 4900 CMYK printer. If you examine the Color Space field, you will see that the printer was being treated as an RGB device when the profile was made. If you are using a printer driver to print to an inkjet printer, only RGB printer profiles will be listed, but if you are using a RIP, CMYK profiles for the same printer should be selected. If you can’t find a profile in a drop-down menu, open the profile and check the header for the Data Color Space information.

5.5.5 Flags

A profile header contains a Flags field. Part of the Flags field is reserved for use by the ICC and is used to specify issues such as whether the profile is embedded in an image



Epson Stylus Pro 4900 4910 EnhancedMattePaper_MK.icc

#	Tag	Data	Size	Description
z	Header		128	
1	'desc'	'desc'	239	Localized description strings
2	'cprt'	'text'	44	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'A2B0'	'mft2'	32,602	Intent-0, 16-bit, device to PCS conversio
6	'A2B1'	'mft2'	32,602	Intent-1, 16-bit, device to PCS conversior

Size: **759,552 bytes**
Preferred CMM: **Apple**
Specification Version: **2.4.0**
Class: **Output**
Space: **RGB**
PCS: **Lab**
Created: **2007-11-13, 11:30 AM**
Platform: **Apple**
Flags: **Best Quality**
Device Manufacturer: **'EPSO'**
Device Model: **'E471'**
Device Attributes: **00000000 00000002**
Rendering Intent: **Perceptual**
PCS Illuminant: **0.96420, 1.00000, 0.82491**
Creator:
MD5 Signature:

Figure 5.8 Examining the Color Space field reveals that an Epson Stylus Pro 4900 CMYK printer is being treated as an RGB device.

or is stand-alone. A color management system vendor, such as ColorSync and the Apple CMM can use the remainder of the field. In the screen snapshots shown in this chapter, we see use of "Normal Quality" and "Best Quality."

ColorSync uses the vendor's part of the Flags field for a quality setting. ColorSync has unilaterally decided on its interpretation for this field (hopefully other vendors will abide by the same interpretation).

Let's look at how the quality setting works. The quality setting controls the quality of the color-matching process in relation to the time required to perform the match. There are three quality settings: Normal, Draft, and Best.

When you start a color-matching session, ColorSync sends the image and the required profiles to the CMM. The Apple CMM extracts the lookup tables it needs from the profiles and produces a new, single lookup table. Using a single lookup table instead of separate lookup tables is a common technique in color processing that speeds up conversion for runtime applications. The size of the new lookup table can be chosen so as to balance memory requirements, accuracy, and speed of processing.

In current implementations, the normal and draft settings do similar things. When these quality settings are used, the Apple CMM is directed to make a new lookup table from the profiles sent to the CMM. In best-quality setting, however, the Apple CMM retains the original lookup tables from the profiles and does not create a merged lookup table.

5.5.6 Rendering Intent

A field in the profile header is for the Rendering Intent. The rendering intent of a profile can be set to perceptual (0), relative colorimetric (1), saturation (2), or absolute colorimetric (3). Profile inspectors may show the numerical value for the rendering intent or may translate this to user-friendly phrase.

The Rendering Intent field is largely redundant today as in many cases software applications will offer a menu selectable choice of rendering intent that will override the entry in the profile header. See for example Figure 5.4, where the perceptual intent within the profile header is being overwritten by the relative colorimetric intent by the Photoshop user.

5.5.7 PCS Illuminant

The PCS illuminant is the reference light source. In a profile header the light source is D50 which has XYZ values of 0.9642, 1.000, and 0.8249. The PCS illuminant is included as a changeable item as the ICC has long-term plans to extend the PCS to include other white points.

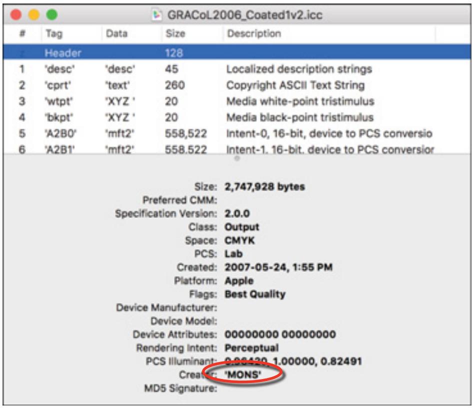
Note that the PCS white point in the header is different from the material/device white point. A profile typically contains two white points – the PCS illuminant white point (D50), and secondly, measurement of the white point of the device being profiled. The PCS illuminant white point is specified in the profile header, while the white point of a monitor or inkjet paper or press condition is specified in the tag table as a media white point tag, Section 5.6.4.

5.5.8 Profile Creator

This is a field that users may often examine as it indicates which profiling program was used to create the profile. Each profiling program may create an ICC profile with its own flavor, as an analogy, users may like the reproduction style of a Nikon or Canon digital camera. Profile-making programs can create very different perceptual rendering intents, different black generation strategies, or lookup tables of different size. Different vendors can also include different tags in the tag table.

Often a profile for the same device is available from different profile creators. Consider the GRACoL 2006 profile. One version of the GRACoL 2006 profile has been created by Monaco Systems and is available from the ICC Profile Registry, Figure 5.9a. This profile is called *GRACoL2006_Coated1v2* and the Creator field is “MONS.” We see that Adobe has provided within Creative Cloud (CC) a different GRACoL profile. The Adobe version of the profile is called *CoatedGRACoL2006* and the Creator field is “Adobe.” These profiles are slightly different, and will create different results; only by examining the Creator field can we be sure which one we are using.

The Creator field should follow the ICC manufacturer signature registry, but the registry is not always up to date, so users must infer the following common creators; Adobe, Apple, CvSp (ColorVision Spyder), HP, LOGO (GretagMacbeth), MONS (Monaco Systems), XRCM (X-Rite), etc.



GRACoL2006_Coated1v2.icc

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'desc'	45	Localized description strings
2	'cprt'	'text'	260	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'A2B0'	'mft2'	558,522	Intent-0, 16-bit, device to PCS conversio
6	'A2B1'	'mft2'	558.522	Intent-1. 16-bit. device to PCS conversior

Size: **2,747,928 bytes**
Preferred CMM:
Specification Version: **2.0.0**
Class: **Output**
Space: **CMYK**
PCS: **Lab**
Created: **2007-05-24, 1:55 PM**
Platform: **Apple**
Flags: **Best Quality**
Device Manufacturer:
Device Model:
Device Attributes: **00000000 00000000**
Rendering Intent: **Perceptual**
PCS Illuminant: **0.96420, 1.00000, 0.82491**
Creator: **'MONS'**
MD5 Signature:

CoatedGRACoL2006.icc

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'desc'	128	Localized description strings
2	'cprt'	'text'	133	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'A2B0'	'mft2'	89,958	Intent-0, 16-bit, device to PCS conversio
5	'A2B1'	'mft2'	89,958	Intent-1, 16-bit, device to PCS conversior
6	'A2B2'	'mft2'	89.958	Intent-2. 16-bit. device to PCS conversio

Size: **654,456 bytes**
Preferred CMM: **Adobe**
Specification Version: **2.1.0**
Class: **Output**
Space: **CMYK**
PCS: **Lab**
Created: **2009-06-26, 12:22 AM**
Platform: **Apple**
Flags: **Normal Quality**
Device Manufacturer: **Adobe**
Device Model:
Device Attributes: **00000000 00000000**
Rendering Intent: **Perceptual**
PCS Illuminant: **0.96420, 1.00000, 0.82491**
Creator: **Adobe**
MD5 Signature:

(a) (b)

Figure 5.9 There are two versions of the GRACoL 2006 profile in common use, one is made by (a) Monaco Systems (MONS) and the other (b) is made by Adobe Systems. They are slightly different. The Creator tag allows us to tell them apart.

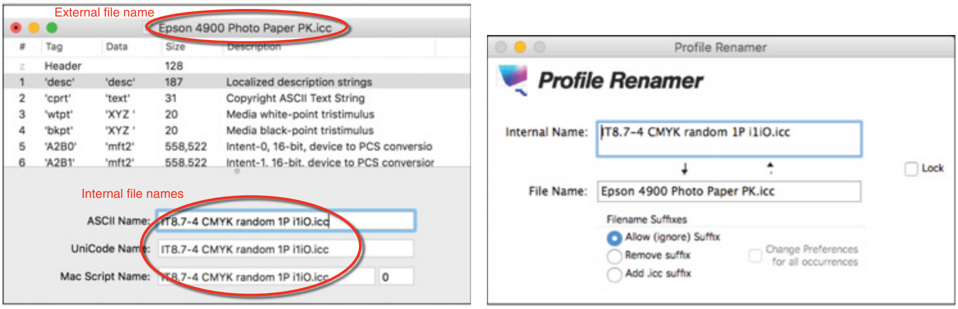
5.6 Tag Table

In contrast to the header, the tags in the tag table can vary, depending on the type of device the profile is for (digital camera, monitor, printer, and so on). The ICC specifies a list of required tags for each class of profile. To be valid, a profile must include all the required tags for the given device class.

Tags can be divided into three categories: ICC required tags, ICC optional tags, and private tags.

5.6.1 Profile Description Tag

Every profile must contain a Profile Description tag – "desc", Figure 5.10a. The description tag stores the name of the profile. Profiles have an external filename and an internal



Epson 4900 Photo Paper PK.icc

#	Tag	Data	Size	Description
z	Header		128	
1	'desc'	'desc'	187	Localized description strings
2	'cprt'	'text'	31	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'A2B0'	'mft2'	558,522	Intent-0, 16-bit, device to PCS conversio
6	'A2B1'	'mft2'	558.522	Intent-1. 16-bit. device to PCS conversior

ASCII Name: IT8.7-4 CMYK random 1P i1iO.icc
UniCode Name: IT8.7-4 CMYK random 1P i1iO.icc
Mac Script Name: IT8.7-4 CMYK random 1P i1iO.icc 0

Profile Renamer

Profile Renamer

Internal Name: IT8.7-4 CMYK random 1P i1iO.icc
File Name: Epson 4900 Photo Paper PK.icc
☐ Lock

Filename Suffixes
● Allow (ignore) Suffix
○ Remove suffix
○ Add .icc suffix
☐ Change Preferences for all occurrences

(a) (b)

Figure 5.10 (a) There are internal names to a profile, which may differ from the external file name. (b) Chromix ColorThink Pro provides the ability to reconcile the internal and external names.

name, Figure 5.10b. The Profile Description tag of a profile can contain up to three different internal names for a profile. The internal names are used for multi-platform and multi-language support.

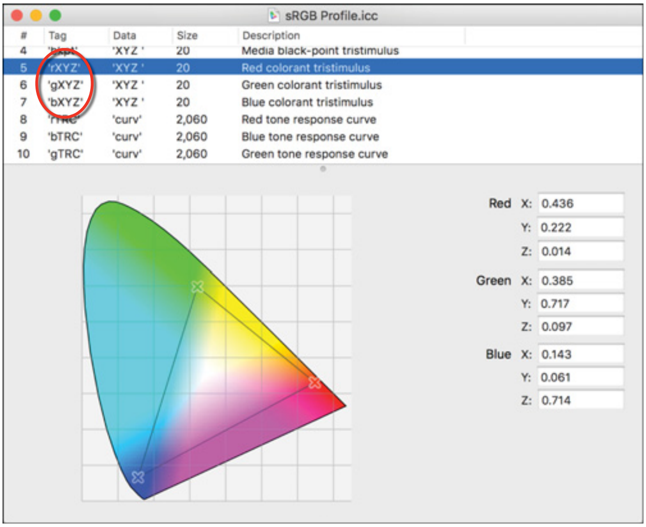
Some programs, such as Photoshop, use the internal name to create its drop-down menus. This can lead to confusion if a user changes the external filename but not the internal name. On the desktop, the user will see a profile with the external file name, while Photoshop will extract the internal filename to create entries in its drop-down menus.

One way of making sure the external name matches the internal name is to use the repair or edit facility in ColorSync Utility. A commercial solution, Chromix ColorThink Pro also allows the user to reconcile the internal and external names, Figure 5.10b.

5.6.2 XYZ Primaries Tag

A device such as a display can be characterized by the color of the screen primaries. Simple, additive devices such as flat panel displays can be adequately characterized by a matrix that, in conjunction with the tone reproduction curve, converts RGB values into XYZ values. During the display profiling process an instrument placed on the face of the monitor measures the chromaticities of the screen's red, green and blue primaries and stores that information in the XYZ primaries tags, Figure 5.11. The chromaticities of the screen primaries are stored as CIE XYZ coordinates, with tag names of rXYZ, gXYZ, bXYZ.

The data in the XYZ primaries tags is used to form a 3 × 3 matrix that can be used to process image data and thus perform a color space conversion.

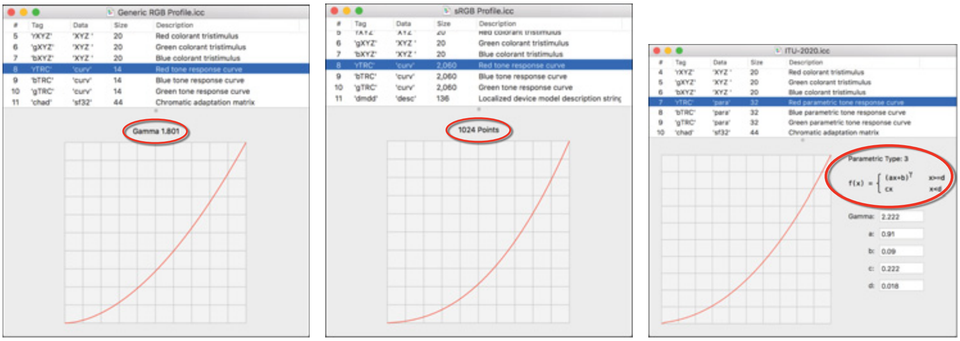


sRGB Profile.icc

#	Tag	Data	Size	Description
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'rXYZ'	'XYZ '	20	Red colorant tristimulus
6	'gXYZ'	'XYZ '	20	Green colorant tristimulus
7	'bXYZ'	'XYZ '	20	Blue colorant tristimulus
8	'rTRC'	'curv'	2,060	Red tone response curve
9	'bTRC'	'curv'	2,060	Blue tone response curve
10	'gTRC'	'curv'	2,060	Green tone response curve

Red	X:	0.436
	Y:	0.222
	Z:	0.014
Green	X:	0.385
	Y:	0.717
	Z:	0.097
Blue	X:	0.143
	Y:	0.061
	Z:	0.714

Figure 5.11 Display profiles are simple profiles based on red, green and blue primaries that form a 3 × 3 matrix.



(a)

Generic RGB Profile.icc

#	Tag	Data	Size	Description
5	'rXYZ'	'XYZ '	20	Red colorant tristimulus
6	'gXYZ'	'XYZ '	20	Green colorant tristimulus
7	'bXYZ'	'XYZ '	20	Blue colorant tristimulus
8	'rTRC'	'curv'	14	Red tone response curve
9	'bTRC'	'curv'	14	Blue tone response curve
10	'gTRC'	'curv'	14	Green tone response curve
11	'chad'	'sf32'	44	Chromatic adaptation matrix

Gamma 1.801

(b)

sRGB Profile.icc

#	Tag	Data	Size	Description
5	'rXYZ'	'XYZ '	20	Red colorant tristimulus
6	'gXYZ'	'XYZ '	20	Green colorant tristimulus
7	'bXYZ'	'XYZ '	20	Blue colorant tristimulus
8	'rTRC'	'curv'	2,060	Red tone response curve
9	'bTRC'	'curv'	2,060	Blue tone response curve
10	'gTRC'	'curv'	2,060	Green tone response curve
11	'dmdd'	'desc'	136	Localized device model description string

1024 Points

(c)

ITU-2020.icc

#	Tag	Data	Size	Description
4	'rXYZ'	'XYZ '	20	Red colorant tristimulus
5	'gXYZ'	'XYZ '	20	Green colorant tristimulus
6	'bXYZ'	'XYZ '	20	Blue colorant tristimulus
7	'rTRC'	'para'	32	Red parametric tone response curve
8	'bTRC'	'para'	32	Blue parametric tone response curve
9	'gTRC'	'para'	32	Green parametric tone response curve
10	'chad'	'sf32'	44	Chromatic adaptation matrix

Parametric Type: 3

$$f(x) = \begin{cases} (ax+b)^{\gamma} & x>=d \\ cx & x<d \end{cases}$$

Gamma: 2.222

a: 0.91

b: 0.09

c: 0.222

d: 0.018

Figure 5.12 The monitor gamma value can be stored as (a) a single gamma value, (b) explicit data points, or (c) as a parametric equation; this allows profile makers some flexibility, while still ensuring interoperability.

5.6.3 Tone Reproduction Curve Tag

Tone reproduction curve (TRC) data is used to characterize a monitor or digital camera. One of the main characteristics of monitors that we would like to measure and record is the display's gamma (contrast) setting because this affects the appearance of displayed images. Profiles can store information relating to the display's gamma. In a monitor profile, the TRC tags represent the gamma of the display.

The data in the TRC tags can be stored in different ways: it can be stored as a single value, Figure 5.12a, or as a lookup table with explicit curve points, Figure 5.12b, or as an equation (parametric curve type), Figure 5.12c. Generally, for well behaved devices, there is expected to be little difference in accuracy between the different methods for encoding TRC information.

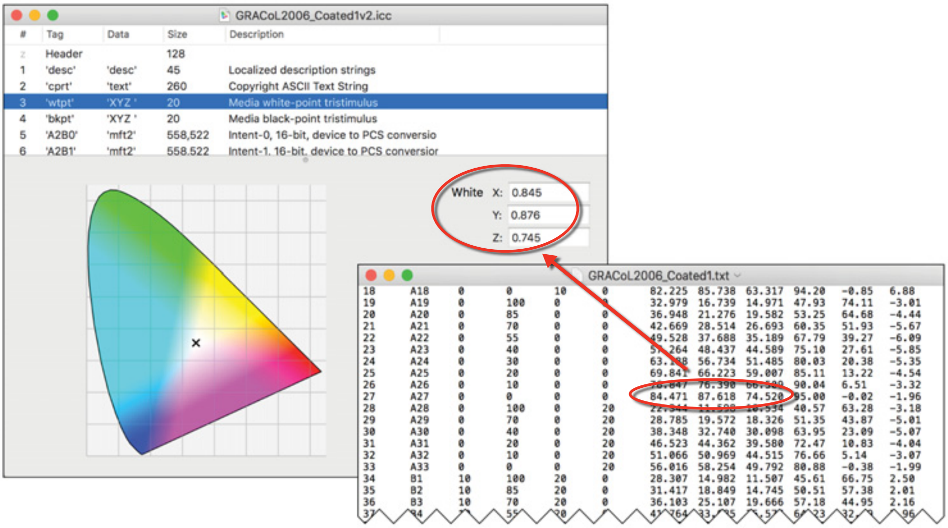
Due to the simplicity of the matrix-TRC construct, monitor and other RGB color space profiles are very easy to construct – all that is needed is the XYZ values of the primary colorants and a TRC tag. Thus you may come across any number of custom RGB profiles such as BruceRGB, DonRGB, ProPhoto RGB, etc.

5.6.4 Media White Point Tag

The Media White Point tag must be included in all profiles and is a measurement of the media, for example measurement of the paper which is the white patch in a paper target or the white point of a display. The Media White Point tag uses units of CIE XYZ. It is reassuring for a user to confirm that the data from a printer measurement file is correctly populated as the media white point, Figure 5.13. If there are color problems in a workflow this tag can be checked to see if any errors occurred in the profile-making process. The data in the Media White Point tag is used for a number of calculations, such as those involving absolute colorimetry.

5.6.5 Chromatic Adaptation Tag

An ICC workflow assumes that the measurements in the measurement file were made using a D50 illuminant. If the illuminant was not D50 then before creating the profile



GRACoL2006_Coated1v2.icc

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'desc'	45	Localized description strings
2	'cprt'	'text'	260	Copyright ASCII Text String
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'bkpt'	'XYZ '	20	Media black-point tristimulus
5	'A2B0'	'mft2'	558,522	Intent-0, 16-bit, device to PCS conversio
6	'A2B1'	'mft2'	558,522	Intent-1, 16-bit, device to PCS conversior

White X: 0.845
Y: 0.876
Z: 0.745

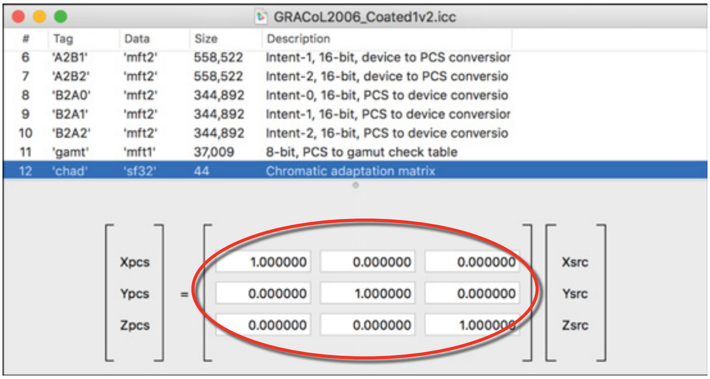
GRACoL2006_Coated1.txt

```
18   A18   0    0     10   0     82.225 85.738 63.317 94.20  -0.85  6.88
19   A19   0    100   0    0     32.979 16.739 14.971 47.93  74.11  -3.01
20   A20   0    85    0    0     36.948 21.276 19.582 53.25  64.68  -4.44
21   A21   0    70    0    0     42.669 28.514 26.693 60.35  51.93  -5.67
22   A22   0    55    0    0     49.528 37.688 35.189 67.79  39.27  -6.09
23   A23   0    40    0    0     57.264 48.437 44.589 75.10  27.61  -5.85
24   A24   0    30    0    0     63.188 56.734 51.485 80.03  20.38  -5.35
25   A25   0    20    0    0     69.841 66.223 59.007 85.11  13.22  -4.54
26   A26   0    10    0    0     76.847 76.390 66.509 90.04  6.51   -3.32
27   A27   0    0     0    0     84.471 87.618 74.520 95.00  -0.02  -1.96
28   A28   0    100   0    20    22.344 11.598 10.534 40.57  63.28  -3.18
29   A29   0    70    0    20    28.785 19.572 18.326 51.35  43.87  -5.01
30   A30   0    40    0    20    38.348 32.740 30.098 63.95  23.09  -5.07
31   A31   0    20    0    20    46.523 44.362 39.580 72.47  10.83  -4.04
32   A32   0    10    0    20    51.066 50.969 44.515 76.66  5.14   -3.07
33   A33   0    0     0    20    56.016 58.254 49.792 80.88  -0.38  -1.99
34   B1    10   100   20   0     28.307 14.982 11.507 45.61  66.75  2.50
35   B2    10   85    20   0     31.417 18.849 14.745 50.51  57.38  2.01
36   B3    10   70    20   0     36.103 25.107 19.666 57.18  44.95  2.16
```

Figure 5.13 Data from a printer measurement file is directly populated as the Media White Point tag (wtpt).

and its contents, mathematical methods must be used to convert from the measured illuminant (perhaps D65) to D50. To do this, the measurement data is adapted from one light source to another, using mathematical methods. There are a number of established chromatic adaptation methods, such as the von Kries transform, the Bradford transform, or a linear rescaling of XYZ values. There are differences between the results obtained when using each type of transform. If the chromatic method is not specified, product A could use a different transform compared to product B and we may see different results. This situation was clarified by the Chromatic Adaptation tag, introduced in v4 profiles.

The method used to convert data is indicated by the contents of a matrix and included within the Chromatic Adaptation tag, Figure 5.14. The XYZ values under the source



GRACoL2006_Coated1v2.icc

#	Tag	Data	Size	Description
6	'A2B1'	'mft2'	558,522	Intent-1, 16-bit, device to PCS conversior
7	'A2B2'	'mft2'	558,522	Intent-2, 16-bit, device to PCS conversio
8	'B2A0'	'mft2'	344,892	Intent-0, 16-bit, PCS to device conversio
9	'B2A1'	'mft2'	344,892	Intent-1, 16-bit, PCS to device conversior
10	'B2A2'	'mft2'	344,892	Intent-2, 16-bit, PCS to device conversio
11	'gamt'	'mft1'	37,009	8-bit, PCS to gamut check table
12	'chad'	'sf32'	44	Chromatic adaptation matrix

$$\begin{bmatrix} Xpcs \\ Ypcs \\ Zpcs \end{bmatrix} = \begin{bmatrix} 1.000000 & 0.000000 & 0.000000 \\ 0.000000 & 1.000000 & 0.000000 \\ 0.000000 & 0.000000 & 1.000000 \end{bmatrix} \begin{bmatrix} Xsrc \\ Ysrc \\ Zsrc \end{bmatrix}$$

Figure 5.14 The Chromatic Adaptation tag (chad) consists of a matrix that encodes the von Kries or Bradford transform or a null matrix as shown here.

illuminant are multiplied by the chromatic adaptation transform matrix values to compute PCS (D50), XYZ values. If the illumination during measurement was D50, then profile-making software can omit inclusion of this tag. However, to improve interoperability, it is advisable for profiling applications to include this tag, even if it includes a null matrix as shown in the figure.

5.6.6 Lookup Table Tags

Lookup table tags may be found in scanner, digital camera, monitor, and printer profiles. A lookup table is fundamental to color management as it is used to convert pixel values from source to destination color space – we may say that color management works via a series of lookup tables. Programs such as Photoshop will use the lookup table information to convert image data, for example, from RGB to L*a*b* and then to CMYK. As lookup table operations are so key to color management the conversion of pixel values through a lookup table is described in more detail with a practical example, in Section 5.9.

Monitor, scanner and digital camera profiles are simpler, additive devices and their color characteristics can often be adequately characterized by the matrix-TRC model that was described earlier. Monitor and digital camera profiles, therefore, only optionally contain a lookup table tag. When both methods are present the CMM will always use the lookup table as this represents a higher-order, better transformation.

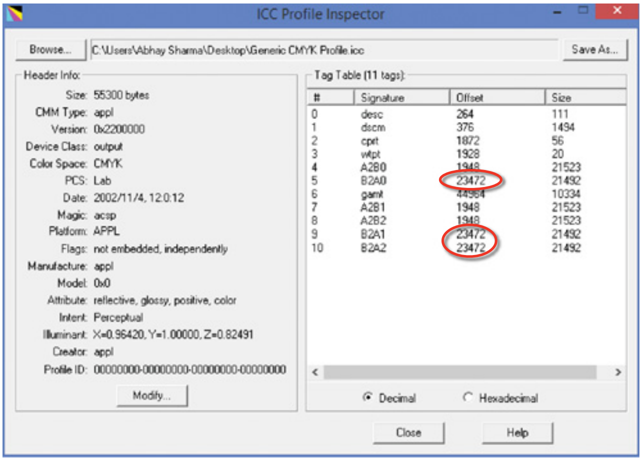
In the case of a printer, proofer or press profiles the complex mixing of cyan, magenta, yellow and black inks, the properties of the ink pigments, and the interaction of a substrate all require a more sophisticated modeling of the color characteristics of the device, so a lookup table is used in all output profile types.

All printer profiles must contain six lookup tables, as listed in Table 5.3. The interpretation of the lookup table tags is that AToBx signifies a device-to-PCS lookup table, whereas the BToAx tag is a PCS-to-device transform. Thus the AToB0 lookup table contains data that can be used to convert image pixel values, for example, from CMYK to L*a*b*, while a BToA0 lookup table can be used to convert pixel data from L*a*b* to CMYK.

There are different lookup tables for each of the rendering intents. So there are tags in a profile for the perceptual lookup tables (A2B0 and B2A0), the relative colorimetric lookup tables (A2B1 and B2A1), and the saturation lookup tables (A2B2

Table 5.3 Output profiles must contain 6 lookup tables for different rendering intents. (The Absolute Colorimetric intent is not stored in a profile, it is created during runtime.)

Rendering intent	Number	Lookup table
Perceptual	0	A2B0/B2A0
Relative colorimetric	1	A2B1/B2A1
Saturation	2	A2B2/B2A2
Absolute colorimetric	3	–



C:\Users\Abhay Sharma\Desktop\Generic CMYK Profile.icc

Header Info:

Size: 55300 bytes
CMM Type: appl
Version: 0x2200000
Device Class: output
Color Space: CMYK
PCS: Lab
Date: 2002/11/4, 12:0:12
Magic: acsp
Platform: APPL
Flags: not embedded, independently
Manufacture: appl
Model: 0x0
Attribute: reflective, glossy, positive, color
Intent: Perceptual
Illuminant: X=0.96420, Y=1.00000, Z=0.82491
Creator: appl
Profile ID: 00000000-00000000-00000000-00000000

Tag Table (11 tags):

#	Signature	Offset	Size
0	desc	264	111
1	dscm	376	1494
2	cprt	1872	56
3	wtpt	1928	20
4	A2B0	1948	21523
5	B2A0	23472	21492
6	gamt	44964	10334
7	A2B1	1948	21523
8	A2B2	1948	21523
9	B2A1	23472	21492
10	B2A2	23472	21492

● Decimal ○ Hexadecimal

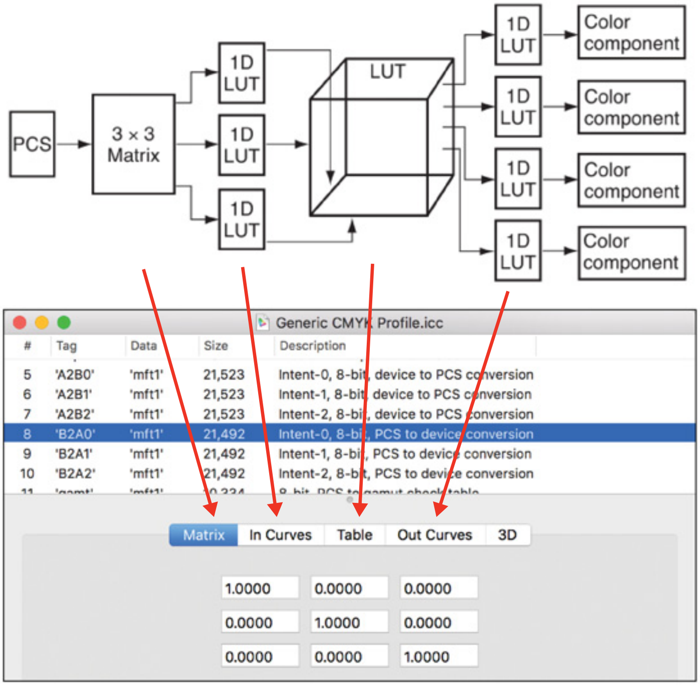
Figure 5.15 By examining the tag offset value, we see that different rendering intents all use the same lookup table.

and B2A2). A profile does not contain a lookup table containing data for the absolute colorimetric rendering intent, instead, if a user requests that an image be processed according to absolute colorimetry, the data from the relative colorimetric lookup table is used to calculate the absolute colorimetric transformation using media white point information from the Media White Point tag.

On examining the tag offset in a profile, we see that the lookup table tags can have identical offsets, Figure 5.15. In this profile for example, the lookup tables for different rendering intents – B2A0, B2A1, and B2A2 – are all using the same tag address, which means that the same data is being reused for different tags. This technique is used in profiles where a vendor must include a number of required lookup table tags to produce a valid ICC profile, but the vendor has not prepared different data for each tag content. Reusing tags can be done in all profile types and is efficient – it reduces file size – but the end user should appreciate that choosing a different rendering intent in such a profile will not make any difference to the processed data.

A lookup table tag has a well-defined internal format, as shown in Figure 5.16. Lookup tables in a v2 ICC profile consist of four parts: a matrix, a set of one-dimensional lookup tables, a multidimensional lookup table, and another set of one-dimensional lookup tables. Pixel values in an image are processed sequentially through each part of these components. The different parts of the lookup table are used to affect the results of the color conversion. The one-dimensional lookup tables may apply a curve to create linear RGB values, the matrix may be used to perform a linear conversion between RGB and XYZ, and one-dimensional curves after the multidimensional lookup table may be used to give greater weight to neutral colors.

It is not necessary for profile-making software to use all elements in a lookup table tag, and in practice they do not. However, the format provides flexibility so that vendors can use what they want and ignore what they do not want. If a vendor does not want to use part of a lookup table tag, the vendor can simply fill these parts of the tag with null values.



Generic CMYK Profile.icc

#	Tag	Data	Size	Description
5	'A2B0'	'mft1'	21,523	Intent-0, 8-bit, device to PCS conversion
6	'A2B1'	'mft1'	21,523	Intent-1, 8-bit, device to PCS conversion
7	'A2B2'	'mft1'	21,523	Intent-2, 8-bit, device to PCS conversion
8	'B2A0'	'mft1'	21,492	Intent-0, 8-bit, PCS to device conversion
9	'B2A1'	'mft1'	21,492	Intent-1, 8-bit, PCS to device conversion
10	'B2A2'	'mft1'	21,492	Intent-2, 8-bit, PCS to device conversion

1.0000	0.0000	0.0000
0.0000	1.0000	0.0000
0.0000	0.0000	1.0000

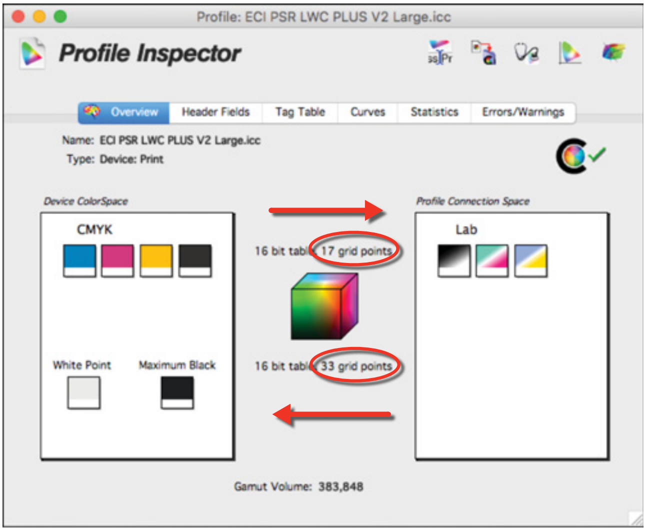
Figure 5.16 In v2 profiles, the "L*a*b* to CMYK" lookup table tag consists of a 3 × 3 matrix, one-dimensional lookup tables, a multidimensional lookup table (LUT), and a final set of one-dimensional lookup tables.

The lookup tables are created by profile-making software, during the profile making process. The resolution, or number of cube nodes in the lookup table, can have direct consequences on the quality of the color transform and thus on the color of the final output. A larger number of cube nodes can greatly improve the color quality of vignettes, highlight and shadow detail, and many other aspects of color reproduction.

In practical situations users may check the number of cube nodes in the lookup table tags, Figure 5.17. In this example, visualized using Chromix ColorThink Pro software, the number of cube nodes in the A2B1 lookup table, i.e. CMYK to L*a*b* is 17 grid points or cube nodes. The A2B1 table is used for proofing. The B2A1 lookup table, i.e. L*a*b* to CMYK, has 33 cube nodes. The B2A1 table is responsible for processing final image data and it is advisable that this table is constructed with a larger number of cube nodes as seen in this example. Users may like to check the number of cube nodes in critical profiles as it has direct implications for color quality.

5.6.7 Target Tag

Profiles can contain a tag called the Target tag, Figure 5.18. This tag contains the measurement data from measurement of the monitor or measurement of the printer characterization target (IT8.7/4 or ECI 2002, etc). This tag is provided so that distributed


Profile: ECI PSR LWC PLUS V2 Large.icc
Profile Inspector
Overview
Header Fields
Tag Table
Curves
Statistics
Errors/Warnings
Device ColorSpace
CMYK
White Point
Maximum Black
16 bit table 17 grid points
16 bit table 33 grid points
Profile Connection Space
Lab

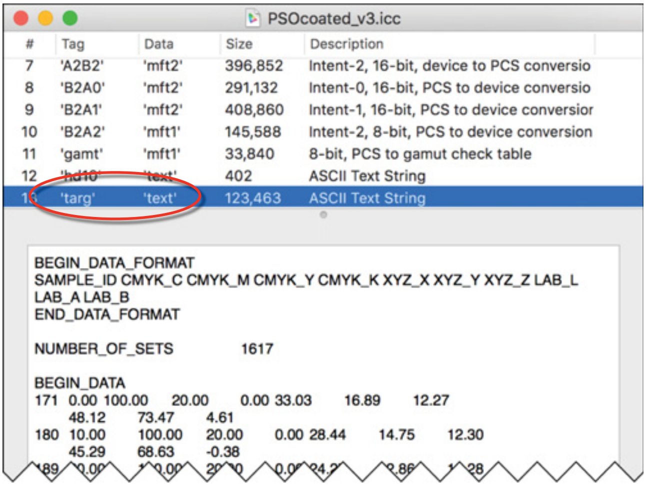
Name: ECI PSR LWC PLUS V2 Large.icc
Type: Device: Print

Gamut Volume: 383,848

Figure 5.17 The number of cube nodes in the CMYK to L*a*b* lookup table (for proofing) is 17, while there are more cube nodes – 33, in the L*a*b* to CMYK lookup table used for processing final data.

utilities can identify the underlying characterization data, create new transforms or check the current performance against the original device measurements.

When a profile's lookup table is generated, in the case of a printer profile, the black generation is determined and encoded within the lookup table. To change the level of black channel generation it is necessary to re-generate the profile from the measurement data. If the data is available within the Target tag, profile-making software can use this information and offer the user the option to regenerate the profile's lookup tables with a new black generation strategy.


PSOcoated_v3.icc

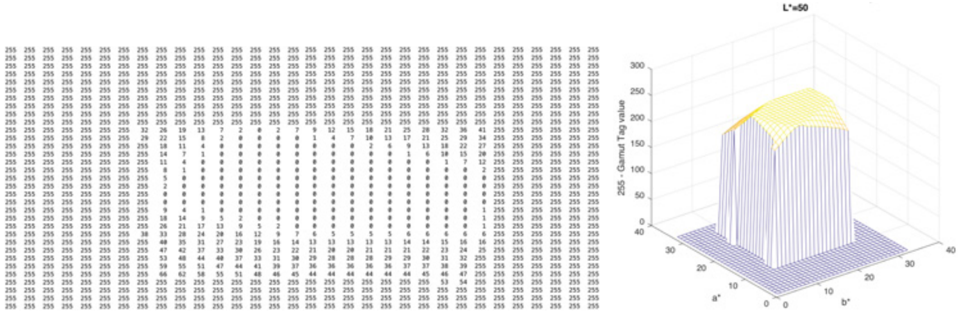
#	Tag	Data	Size	Description
7	'A2B2'	'mft2'	396,852	Intent-2, 16-bit, device to PCS conversio
8	'B2A0'	'mft2'	291,132	Intent-0, 16-bit, PCS to device conversio
9	'B2A1'	'mft2'	408,860	Intent-1, 16-bit, PCS to device conversior
10	'B2A2'	'mft1'	145,588	Intent-2, 8-bit, PCS to device conversion
11	'gamt'	'mft1'	33,840	8-bit, PCS to gamut check table
12	'hd10'	'text'	402	ASCII Text String
13	'targ'	'text'	123,463	ASCII Text String

```
BEGIN_DATA_FORMAT
SAMPLE_ID CMYK_C CMYK_M CMYK_Y CMYK_K XYZ_X XYZ_Y XYZ_Z LAB_L
LAB_A LAB_B
END_DATA_FORMAT

NUMBER_OF_SETS          1617

BEGIN_DATA
171  0.00  100.00     20.00      0.00  33.03      16.89      12.27
     48.12      73.47      4.61
180  10.00      100.00     20.00      0.00  28.44      14.75      12.30
     45.29      68.63      -0.38
```

Figure 5.18 Profiles can store the measurement data in a "targ" (target) tag.



255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	32	26	19	13	7	2	0	2	7	9	12	15	18	21	25	28	32	36	41	255	255	255	255	255	255
255	255	255	255	255	255	255	29	22	15	8	2	0	0	0	0	1	4	7	10	13	17	21	25	29	34	255	255	255	255	255	255
255	255	255	255	255	255	255	255	18	11	4	0	0	0	0	0	0	0	0	2	6	9	13	18	22	27	255	255	255	255	255	255
255	255	255	255	255	255	255	255	14	7	1	0	0	0	0	0	0	0	0	0	0	1	6	10	15	20	255	255	255	255	255	255
255	255	255	255	255	255	255	255	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	12	255	255	255	255	255	255
255	255	255	255	255	255	255	255	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	255	255	255	255	255	255
255	255	255	255	255	255	255	255	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	255	255	255	255	255	255
255	255	255	255	255	255	255	255	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	255	255	255	255	255	255
255	255	255	255	255	255	255	255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	255	255	255	255	255	255
255	255	255	255	255	255	255	255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	255	255	255	255	255	255
255	255	255	255	255	255	255	255	9	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	255	255	255	255	255	255
255	255	255	255	255	255	255	255	18	14	9	5	2	0	0	0	0	0	0	0	0	0	0	0	0	1	255	255	255	255	255	255
255	255	255	255	255	255	255	255	26	21	17	13	9	5	2	0	0	0	0	0	0	0	0	0	0	1	255	255	255	255	255	255
255	255	255	255	255	255	255	38	33	28	24	20	16	12	9	7	6	5	5	5	5	6	6	6	6	6	255	255	255	255	255	255
255	255	255	255	255	255	255	255	40	35	31	27	23	19	16	14	13	13	13	13	13	14	14	15	16	16	255	255	255	255	255	255
255	255	255	255	255	255	255	255	47	42	37	33	30	26	23	22	21	20	20	21	21	21	22	23	24	25	255	255	255	255	255	255
255	255	255	255	255	255	255	255	53	48	44	40	37	33	31	30	29	28	28	28	29	29	30	31	32	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	59	55	51	47	44	41	39	37	36	36	36	36	36	37	37	38	39	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	66	62	58	55	51	48	46	45	44	44	44	44	44	44	45	46	47	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	53	54	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255

(a)

(b)

Figure 5.19 (a) The a*b* slice of the Gamut tag in a profile is shown at L* = 50. This plane has in-gamut values shown by 0 and the extremities of the L*a*b* color space have out-of-gamut, non-zero values. (b) This plane can also be visualized in 3D, where the data is inverted to enable visibility.

It is a useful, "best practice" to retain the measurement data within a profile, so the ICC has provided a tag type for vendors that would like to do this.

5.6.8 Gamut Tag

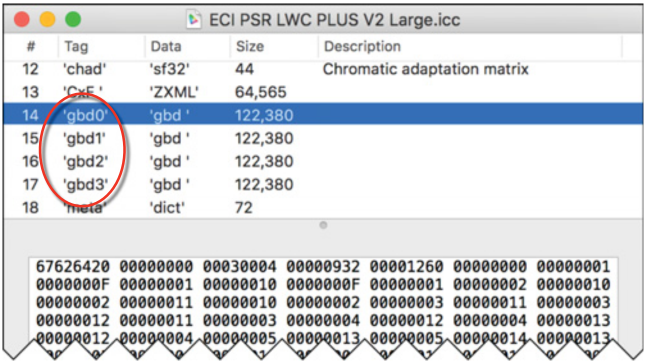
The Gamut tag provides information on out-of-gamut colors, and is a required tag in printer profiles, Figure 5.19. Printing systems tend to have a comparatively small color gamut (compared to RGB devices), and colors from digital camera images may not be reproducible because they are outside the gamut ability of the printer. It is useful when processing an image to alert the user if the destination device cannot reproduce a color. The Gamut tag within an output profile indicates which pixels are in or out of gamut and can help us predict which colors the device can or cannot accurately reproduce.

The Gamut tag of the GRACoL 2006 ICC profile is shown in Figure 5.19a. The figure shows the a^*b^* plane of a 33 × 33 × 33 lookup table at 50 L^*. We see that in this plane, in-gamut values are shown by 0 and out of gamut values are indicated by non-zero values. We also note that the table contains numbers that are between 0 and 255, so the system is not binary or quantized and the query for whether an L*a*b* color is in or out of gamut can return a value that is a qualifier. The same information is visualized in three-dimensions, Figure 5.19b. Given an L*a*b* value, it can be looked up in this lookup table and return an "in-gamut" or "out-of-gamut" response that can be communicated to the user via software that color codes or stains an image.

Unfortunately, few applications use the gamut tag because many profiles have gamut tags that do not produce good results. Given that the Gamut tag is a required tag, it is a shame that the tag is not used to its full extent. Many vendors do not rely on the data in the gamut tag; instead, they build their own edge-of-gamut limits from data within the profile.

5.6.9 Optional Tags

In addition to the required tags, there are other tags recognized and sanctioned by the ICC. These are called optional tags.



ECI PSR LWC PLUS V2 Large.icc

#	Tag	Data	Size	Description
12	'chad'	'sf32'	44	Chromatic adaptation matrix
13	'CxF '	'ZXML'	64,565	
14	'gbd0'	'gbd '	122,380	
15	'gbd1'	'gbd '	122,380	
16	'gbd2'	'gbd '	122,380	
17	'gbd3'	'gbd '	122,380	
18	'meta'	'dict'	72	

```
67626420 00000000 00030004 00000932 00001260 00000000 00000001
0000000F 00000001 00000010 0000000F 00000001 00000002 00000010
00000002 00000011 00000010 00000002 00000003 00000011 00000003
00000012 00000011 00000003 00000004 00000012 00000004 00000013
00000012 00000004 00000005 00000013 00000005 00000014 00000013
```

Figure 5.20 Profiles made with X-Rite software contain private tags – "gbd0", "gbd1", etc. as registered in the ICC private tag registry.

Inclusion of these tags is, as the name suggests, optional, and the absence of these tags should not cause an application to stop functioning or be unable to open and use a profile. Vendors can use optional tags to improve the performance of a profile or system. Optional tags can be used to enhance color transformations or to provide PostScript Level 2 support, calibration support, black and white point mapping, and so on.

Examples of optional tags are the luminance tag (lumi), which can be used to store the luminance of monitors in candelas per square meter; the measurement tag (meas), which can store an alternative measurement specification such as a D65 illuminant instead of the default D50; and a black generation tag (bfd).

5.6.10 Private Tags

The ICC allows the use of private tags, which vendors can use to incorporate proprietary data, often called "secret sauce", Figure 5.20. If a vendor includes private tags in a profile, and you process your image within that vendor's color-processing software, you will get increased functionality and better results, or at least that is what the vendor will claim!

Private tags must be registered and listed in the ICC's private tag registry. Private tags allow CMM developers to add proprietary value to their color management system. By registering just the tag name, developers are assured of maintaining their secrecy and proprietary advantages while maintaining compatibility with the ICC specification.

The use of private tags allows vendors to differentiate their products. However, since the overall philosophy of the ICC is to maintain an open, cross-platform environment, the use of private tags is discouraged and developers are instructed to keep the use of private tags to an absolute minimum.

5.7 Version 2 and Version 4 Profiles

The v2 ICC profile format specification has been in use for a number of years and is well accepted by profile makers and profile users alike. For the majority of workflows the v2 profile architecture and v2-compliant CMMs work without issue, but there are some select cases where users can get different results from concatenation of the same profile pair. A number of changes have been introduced in the v4 profile specification, last updated in 2010. The changes (i) seek to remove ambiguity in the specification and (ii) introduce new formats and structures for profile builders and CMMs.

Occasionally some confusion arises due to changes in the ICC specification. In the early ICC specification scanner profiles had only one lookup table, called the AToB0 tag. In the 1998 specification, the AToB1 and AToB2 tags for the scanner profile were mentioned but were undefined. In recent ICC specifications all lookup tables are defined so that a scanner profile can contain the same set of lookup tables as all other profile types.

A number of the other changes between v2 and v4 profiles have been described in this chapter, including the new requirement to have a Chromatic Adaptation tag and the introduction of an advanced lookup table type with more multi-processing elements. Advanced applications have needed a clearer definition of the profile connection space (PCS) and a salient feature of the v4 specification is the introduction of the Perceptual Reference Medium Gamut (PRMG) that improves interoperability between profile pairs.

In moving to the adoption of v4 profiles it is not necessary to have an exclusive v4 workflow, as v2 and v4 profiles can be used simultaneously.

The ICC philosophy is all about consistency and predictability, so we see that most of the changes from v2 to v4 profiles are on ongoing effort by the ICC to reduce any sources of ambiguity during color processing.

5.8 Version 5 Profiles and iccMAX

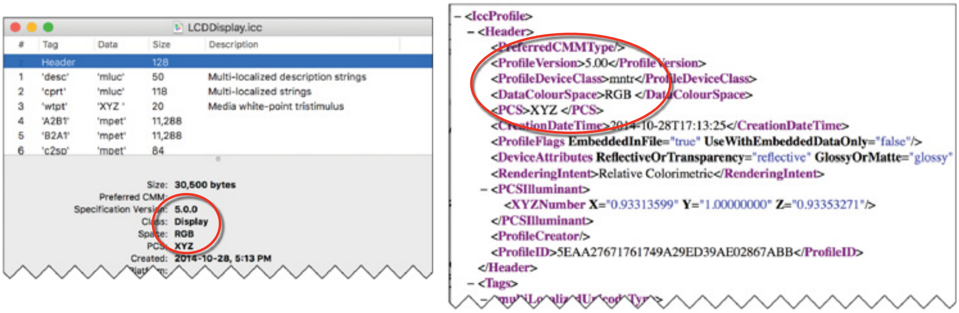
The first generation of ICC architecture is known as ICC.1 and defines v2 and v4 profiles. iccMAX is a new generation architecture with v5 profiles. iccMAX is not intended as a replacement for the existing ICC.1 architecture, it is more an extension or alternative where requirements cannot be fully met by ICC.1. Some of the areas covered by iccMAX include: multi-spectral systems, medical imaging, package printing, color appearance modeling, fine art, three-dimensional rendering, and color information archiving. Generally speaking iccMAX is considered an “extended” color management system for various specific color workflow applications.

The development of iccMAX is closely associated with Max Derhak, Principal Scientist, ONYX Graphics, who is also co-Chair of the ICC in 2017.

There are a number of potential improvements in the iccMAX architecture. The profile connection space (PCS) can be extended from the colorimetric (XYZ or L*a*b*) encoding to encompass a spectral PCS that can account for reflectance, transmission, emission and bi-spectral (fluorescent) spectra.

The iccMAX architecture supports various “profile connections” where data can be added to the color processing pipeline via XML files. Examples of profile connections could be tint based colors, spectral connections for the light source, material connections for overprint visualization, bio-markers for visualization of medical slides, spot color CxF data, etc.

While the encoding of iccMAX ICC profiles remains hexadecimal, there is an increased use of XML for information interchange. An ICC profile for example can be



LCDDisplay.icc

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'mluc'	50	Multi-localized description strings
2	'cprt'	'mluc'	118	Multi-localized strings
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'A2B1'	'mpet'	11,288	
5	'B2A1'	'mpet'	11,288	
6	'c2sp'	'mpet'	84	

Size: 30,500 bytes
Preferred CMM:
Specification Version: 5.0.0
Class: Display
Space: RGB
PCS: XYZ
Created: 2014-10-28, 5:13 PM

```
– <IccProfile>
  – <Header>
      <PreferredCMMType/>
      <ProfileVersion>5.00</ProfileVersion>
      <ProfileDeviceClass>mntr</ProfileDeviceClass>
      <DataColourSpace>RGB </DataColourSpace>
      <PCS>XYZ </PCS>
      <CreationDateTime>2014-10-28T17:13:25</CreationDateTime>
      <ProfileFlags EmbeddedInFile="true" UseWithEmbeddedDataOnly="false"/>
      <DeviceAttributes ReflectiveOrTransparency="reflective" GlossyOrMatte="glossy"
      <RenderingIntent>Relative Colorimetric</RenderingIntent>
    – <PCSIlluminant>
        <XYZNumber X="0.93313599" Y="1.00000000" Z="0.93353271"/>
      </PCSIlluminant>
      <ProfileCreator/>
      <ProfileID>5EAA27671761749A29ED39AE02867ABB</ProfileID>
    </Header>
  – <Tags>
```

Figure 5.21 ICC profiles can be converted into XML encoding in order to facilitate editing of the information.

converted between the ICC format and XML representation, Figure 5.21. Many of the iccMAX data structures can be stored, imported and exported as XML encoding. This allows for profiles to be converted to a textual representation that can be directly edited using a text editor and then converted back to ICC/iccMAX profile formats.

iccMAX introduces the concept of an Interoperability Conformance Specification (ICS). The concept of an ICS is that it is not necessary for each implementation to include all components or tags; software or hardware may claim partial conformance by reading or writing profiles that contain a subset of the ICC tags as defined by a specific ICS. The iccMAX concept defines a platform on which multiple subsets can be defined using separate ICS documents – which is a separate concept from the ICC.1 approach where a single CMM seeks to implement all profile components.

iccMAX is published as an ICC specification (ICC.2) and its own standard, ISO 20677. Many workflows and specifications are based on ICC.1 which will continue to work without any need to change – the industry will suffer minimum disruption if the existing architecture is left unaltered, iccMAX is an extension to the current color processing workflows.

At the time of publication of this book, the iccMAX ICC specification has been published, while its ISO standard, ISO 20677 is progressing through the international committees. Like all emerging technologies, it is too early to predict how well iccMAX will be accepted and incorporated into various industries. With a reference implementation now available, early adopters of iccMAX may find ways of taking advantage of the new system's various capabilities. Others may wait for either an ISO standard to be approved or demonstrated market demand before investing resources to create independent implementations. Only time will tell.

5.9 How Does a Lookup Table Work?

Let us understand the math in a printer profile's lookup table to gain a greater appreciation of how color management actually works. We use a profile inspector to look inside and analyze the contents of a lookup table.

The example presented here uses a legacy profile inspector and legacy printer profiles, however this is real data and is a valid example that serves to illustrate the working of a

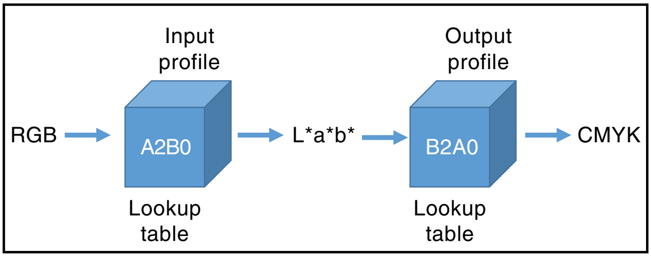


Figure 5.22 An input profile maps RGB values to L*a*b*. The output profile converts L*a*b* values into CMYK. The example in the text considers the output profile lookup table.

profile's lookup tables. (We use an older version of the profile inspector as it very clear and easy to understand.)

In an imaging system RGB values from input devices such as scanners or digital cameras, are converted into the central connection space using input profiles, Figure 5.22. To print the image, the color information is translated out of the connection space into appropriate CMYK values using one of the lookup tables in the output profile. The central connection space is specified in terms of L*a*b* while the device space is CMYK.

An input profile contains a lookup table that relates RGB to L*a*b*, and the output profile contains another lookup table where the L*a*b* values are converted into CMYK values appropriate for a particular printer.

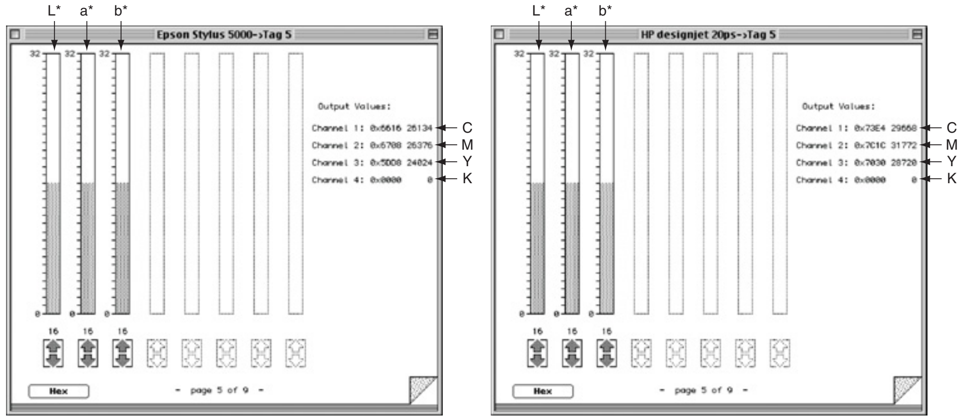
How does a lookup table work? Consider only the printing part, the output profile in the process, Figure 5.22. A color management system specifies in L*a*b*, the color that is needed in part of an image. The role of the output profile lookup table is to convert this color specification into device instructions that can be sent to the printer to generate this color. To print the pixel color, we need to know how much C, M, Y, and K to deposit on the media. A printer profile contains an L*a*b*-to-CMYK lookup table so that for a given L*a*b* value, the output profile tells us what CMYK values should be sent to the printer to create this color.

In ColorSync Profile Inspector (macOS 9), it is very easy to analyze the content of a lookup table – ColorSync Utility in macOS X is too confusing for this example! Figure 5.23a shows the lookup table of the B2A1 tag of an Epson Stylus 5000 proofer. This table provides the L*a*b*-to-CMYK mapping for the absolute colorimetric intent of the printer profile. It is possible to look up any L*a*b* value using the three columns at the left in Figure 5.23 and read the corresponding CMYK value at the right of the figure.

The first column on the left in Figure 5.23a is the L* value. The scale goes from 0 to 100 L*, and thus this color has about 50 L*. The next two columns are for a* and b*. The scale on these columns ranges from −128 to +128. The example shown therefore, has a* and b* values of 0 (i.e. neutral). The color selected to look up, has a L*a*b* of 50, 0, 0.

The corresponding CMYK values are shown as the four output values at the right of Figure 5.23a. In this case, the four channels refer to CMYK. Here the output values are scaled from 0 to 65535. So cyan is $26134/65535 \times 100 \approx 40\%$. This lookup table suggests that sending to the Epson printer 40%C, 40%M, 37%Y, 0%K can create a mid-gray color that is expected to have an L*a*b* of about 50, 0, 0.

Now consider the same profile lookup table, but for a different printer, the HP Designjet 20ps, Figure 5.23b. Let us look at the entry in this lookup table for the same L*a*b*



(a)

```
Output Values:

Channel 1: 0x6616 26134
Channel 2: 0x6708 26376
Channel 3: 0x5DD8 24024
Channel 4: 0x0000     0
```

(b)

```
Output Values:

Channel 1: 0x73E4 29668
Channel 2: 0x7C1C 31772
Channel 3: 0x7030 28720
Channel 4: 0x0000     0
```

Figure 5.23 A legacy macOS 9 profile inspector is still the best way to visualize the (a) L*a*b*-to-CMYK lookup table of an Epson 5000 printer profile, and (b) the same lookup table in an HP Designjet 20ps.

values considered in the previous example. To reproduce L*a*b* of 50, 0, 0 on this printer, the lookup table suggests that the printer be sent CMYK dot% values of 45%C, 48%M, 44%Y, 0%K. Each lookup table contains instructions tailored to a specific device, and this is how the profiling process can achieve the same color on different devices.

In real image processing, perhaps the incoming pixel value has L*a*b* value of 49,0,0 or 48,0,0. Intermediate values are looked up using a procedure called interpolation. The intermediate value is mathematically determined by looking at the adjacent values in the lookup table. Earlier we described the effect of the number of cube nodes in a lookup table, now we can see that a larger number of cube nodes means more cube nodes and any value will have a nearer neighbor and better accuracy.

A lookup table is fundamental to color management as it is how the process of color management actually takes place. Programs such as Photoshop or a RIP would process an image pixel by pixel through this lookup table.

5.10 Summary

This chapter described how ICC profiles are made in accordance with the ICC Specification, (or equivalent standard). When profiles are made in accordance with these documents it ensures that everybody can make an ICC profile and everybody can easily use an ICC profile.

The chapter used tools called profile inspectors. These are simple (and usually free) software programs that allow the user to display the contents of an ICC profile.

This chapter described the two main parts of an ICC profile: the header and the profile tags. We saw that the header has a number of fixed fields. The fixed nature of the header means that application programs such as Photoshop can rely on finding this data, for example, to form drop-down menus that contain profile names.

We looked at the three types of tags that can be found in profiles: ICC required, ICC optional, and private tags. We looked at the required tags for each profile class that must be present to create a valid ICC profile. We saw that the tag requirements were different for input, monitor, and printer profiles.

Looking inside profiles provides us with a stronger position from which to optimize the profiling process, and it is often the only way to identify and troubleshoot problems in a color-managed workflow. For example, a common problem arises when a user clicks on the desktop file icon and changes the external file name of a profile. This can cause the profile to disappear from Photoshop's menus. If you look inside a profile, you can quickly see what the problem is and correct it. Another reason to look inside profiles is to look at the number of cube nodes in the lookup table. If your profile does not use the maximum allowable number of nodes, you may not be getting the best results.

The ICC philosophy is all about consistency and predictability, so we see that the introduction of the mandatory Chromatic Adaptation tag in v4 profiles as a continuous effort by the ICC to reduce any sources of ambiguity during color processing. Other differences between v2 and v4 profiles were considered, such as the introduction of the Perceptual Reference Medium Gamut, which is a clearer definition of the PCS. Moving forward iccMAX (v5) profiles and architecture were described, including the associated use of XML technologies.

An example of how to read the data in a profile lookup table was presented using a real-life example of two different inkjet proofers. This example demonstrated on a fundamental level how lookup tables work and thus, how many operations in color management are carried out.

This chapter contains reference material that the reader may need to return to once we start to apply and use ICC profiles in practical applications.

6

Managing Color in Digital Cameras

Objectives

- Explain color management for digital cameras.
- Review color management procedures for flatbed scanners.
- Identify significant differences between scanner profiling and camera profiling.
- Describe JPEG and camera RAW workflows for digital imaging.
- Review software including Photoshop's Camera Raw and Adobe Lightroom.
- Explain the benefits of the Digital Negative format (DNG).

6.1 Introduction

Today, low, mid and high end digital cameras, and smartphones and tablets are widely used to capture, store, and share digital images. In recent years these capture systems have increased in resolution and performance, and reduced in price. Good quality digital capture is readily available to every level of user from consumer to professional.

This chapter deals with color management for digital cameras and digital capture devices. Images from a digital camera can, and should have an associated ICC profile. The profile provides an accurate representation of the expectations for the colors in the image for subsequent editing, viewing, printing and online publishing.

There used to be a distinction in terms of color management between consumer digital cameras, professional digital SLRs and high-end scanning back cameras. Today this distinction has largely disappeared and, in general, there is little distinction between the color management approaches available in all levels of digital photography.

The profiling process for scanners is well established. Scanners can be used to digitize photographic originals. Scanner profiles are relatively easy to make, and because they are closely-controlled devices – you close the lid on a flatbed scanner, which fixes the lighting – the profiles you get are very effective. Film scanners and flatbed scanners are rarely used anymore, however, scanner profiling is reviewed in this chapter in order to create a foundation from which to discuss digital camera color management.

In terms of color management there is a significant, fundamental difference between the color management approach for scanners versus digital cameras. Scanners create a *facsimile copy* and reproduce exactly what is presented to them – because they can.

Understanding Color Management, Second Edition. Abhay Sharma.
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Digital cameras cannot reproduce the dynamic range of real-world scenes, so instead of a facsimile reproduction, digital cameras render image colors to create a pleasing result.

Often users simply extend the scanner profiling process to digital cameras. For many reasons, as described in this chapter, this will not work. In the first edition of this book, published in 2004, we wrote that.... "there are a number of issues with camera profiling, and at this point there is little consensus on the correct procedure." A number of commercial solutions have come and gone, and today we are happy to report that practitioners and experts have converged on an accepted color management approach for digital cameras.

Today digital camera profiling is much simplified, we simply process the camera image to an RGB color space and then associate the RGB color space profile with the image as it enters various color workflows. The correct process has been identified and agreed upon, and the tools and software to support this new way of working are described in this chapter.

There are two commonly-used digital camera settings; digital photographers can shoot directly to a fully-processed, ready to use JPEG image, or photographers may select an intermediate, un-processed file format called RAW. This chapter considers the color management procedures that apply to these two primary digital camera workflows. A raw file format, called Digital Negative (DNG), is described, in order to create an archival, permanent file format for digital images.

A studio setup for color reproduction for art work creates a special color management situation as the lighting can be closely controlled, so the case of studio color management is dealt with in this chapter.

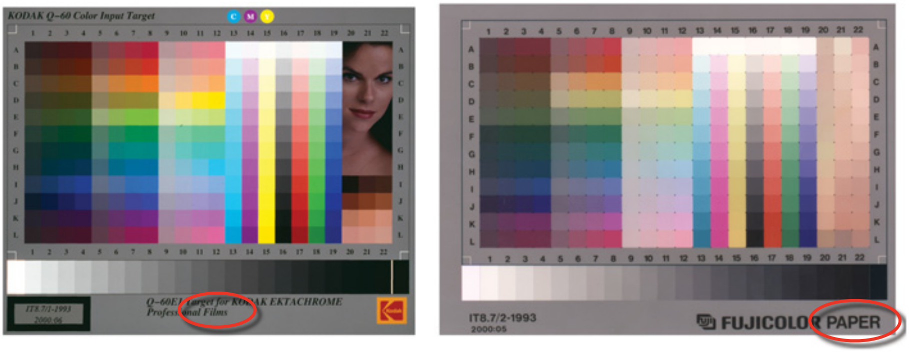
6.2 Scanner Profiling

The scanner profiling process is well established, and works well because (i) scanners are closely-controlled devices – you close the lid on a flatbed scanner, which fixes the lighting, and (ii) the sample is usually a photograph (and not a real scene with a high dynamic range). Here we describe the process of making a scanner profile and then explain how it can be used and applied in Adobe Photoshop.

6.2.1 Making a Scanner Profile

Color managing a scanner is a two-stage process; first a profile is made for a scanner, then an image is scanned and the profile is associated with the scanned image. To make a scanner profile, you need a test chart and its reference file. You choose a test chart according to the type of material you are going to scan, Figure 6.1. If you are going to scan transparency material, you need a test chart that is made on transparency film. This chart is called the IT8.7/1 chart and is shown in Figure 6.1a. If you are profiling the scanner for use with reflection prints, you need to use the IT8.7/2 chart that comes as a 5 × 7-inch photographic print, Figure 6.1b. We see that in scanner profiling, the test chart and subsequent scanned samples are of the same type; film charts are matched to film samples and paper charts are matched to paper samples. And users would usually also even match the manufacturer, for example, Kodak or FujiFilm.

The profiling process begins by scanning the test chart on your scanner, Figure 6.2a. Profile-making software will detect individual elements in the scanned chart image,


KODAK Q-60 Color Input Target
C M Y
Q-60E1 Target for KODAK EKTACHROME Professional Films
IT8.7/1-1993 2000:06
IT8.7/2-1993 2000:05
FUJICOLOR PAPER

(a) (b)

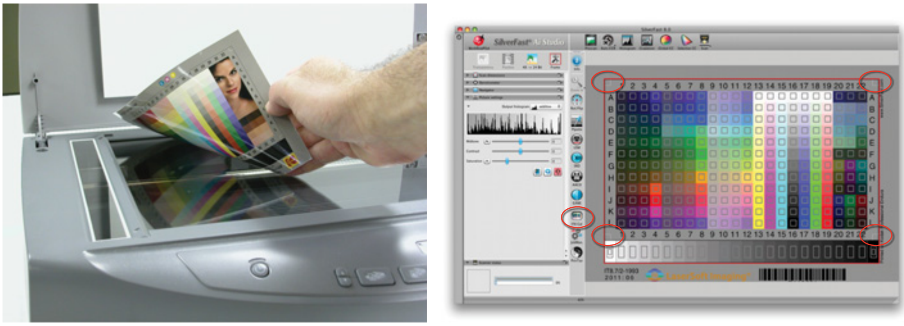
Figure 6.1 (a) The IT8.7/1 is a transparency scanner target produced on film material and (b) the IT8.7/2 is for reflection prints produced on photographic paper. In both instances, columns 20–22 are used to evaluate all-important skin tones.

Figure 6.2b, and, using a reference file will generate a scanner profile and allow you to give it a name and save it. Next, you use your scanner to scan and digitize photographic originals. The scanner profile you just made should be associated with scanned images. The profile can be embedded in the image, or it may be directly applied to the image by the scanner software, or the user may choose to pair up the image and the profile at a later date.

Note that a scanner profile will not normally correct a poor original; it only ensures that you can accurately reproduce the original. Thus if you have a low-contrast, washed-out original, a scanner profile will allow you to reproduce this poor result – accurately!

6.3 Paradigm Shift from Scanners to Digital Cameras

There is a major difference between the color management approach for a scanner versus a digital camera. For a scanner we can use an IT8 chart and make and apply a custom



(a) (b)

Figure 6.2 (a) To make a scanner profile, an IT8 chart is placed on a scanner, (b) SilverFast Ai Studio software creates an ICC profile by identifying the corners and all the patches within the chart. Image (a) *Source:* Courtesy of Rich Adams.

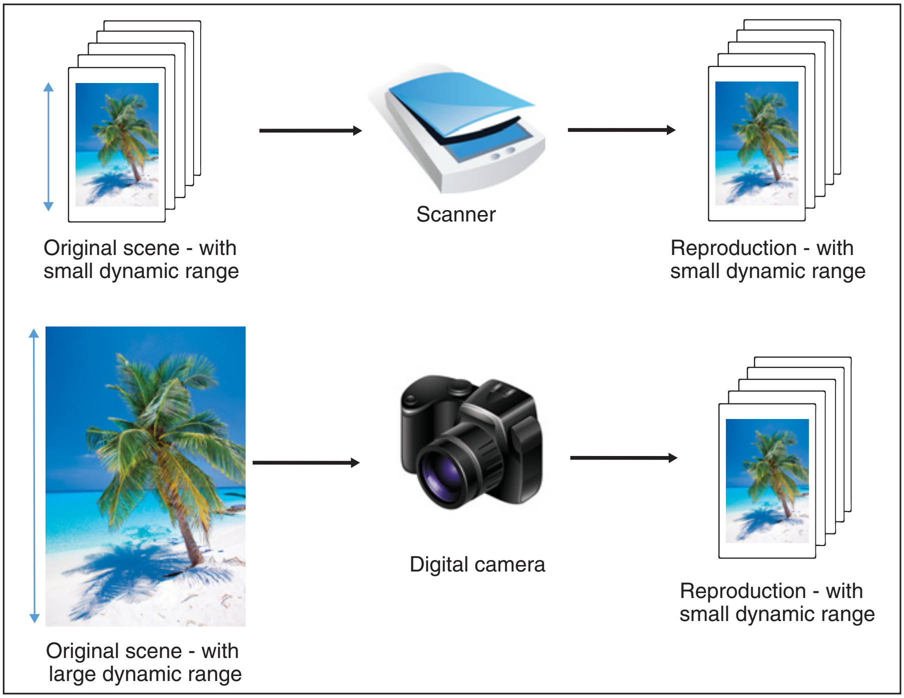

Original scene - with small dynamic range
Scanner
Reproduction - with small dynamic range
Original scene - with large dynamic range
Digital camera
Reproduction - with small dynamic range

Figure 6.3 A scanner can create a facsimile reproduction as the original and reproduction have similar dynamic range. For a digital camera, a typical outdoor scene has a large dynamic range that must be compressed during capture.

input profile. For digital photography, input profiles are definitely used and associated with images from a digital camera, but there is usually no need to create a custom profile.

To understand the difference between scanner and camera color management, consider the dynamic range of the “input scene” for a scanner versus a digital camera. Dynamic range is defined as the difference in light level from light to dark, from highlight to shadow. A scanner may be presented with a photographic print, while a digital camera is presented with an outdoor scene, Figure 6.3.

A transparency or photograph has already been compressed in terms of dynamic range. The difference between the highlight and shadow in a printed photograph is perhaps only 200 : 1, or 7.6 f-stops. A scanner is presented with a low dynamic range image which the sensor can accurately reproduce. An ICC profile can be used to create a 1 : 1 facsimile copy of the original, because the dynamic range of the original and the reproduction are similar.

The input for a digital camera is a real scene. The dynamic range in a real outdoor scene, may be 100,000 : 1, photographers may express this as a range of 20 f-stops. A digital camera, with a similar CCD sensor to a scanner, is not able to record the wide dynamic range found in most outdoor scenes. Digital cameras are not able to deal with this exposure latitude and can either expose for the highlights or the shadows (or use a high-dynamic range solution). Whatever the approach, there is no ability for a digital camera to create a 1 : 1 facsimile, or accurate color reproduction of a high-dynamic range scene, so an ICC input profile for colorimetric reproduction is not appropriate.

In digital photography, it may seem counter-intuitive, but in terms of color, we do not want the reproduction to match the original. In photography there is no interest in making the color of a palm tree in the scene exactly the same color in the reproduction. Because of the way we see color when on the beach compared to looking at your pictures later on, on your laptop, a pleasing image that conjures up pleasant memories will *not* be an exact color match between the original and the digital reproduction. In fact, if the colors were an exact match, the image would often not be acceptable. (This scenario is not new, even in film-based photography there was never the intention for the color to be identical between the scene and the prints you hold in your hand.) For this reason again, a scanner-like input profile is not appropriate for digital camera systems.

During profiling of any device – printer, scanner, digital camera – it is necessary to capture or print a test chart without any edits or color corrections, in other words with color management “turned off.” This is easy to do with scanners, but with digital cameras this is not that easy. As we describe in this chapter, even a un-edited image from a digital camera must undergo some unravelling and rendering of the raw pixel data, so it is difficult to use a digital camera to acquire a totally unprocessed image of a camera test chart for profiling purposes.

It is important to consider the lighting conditions during digital camera profiling. A fundamental tenet of the ICC system is that the conditions at the time of profile generation should be not be changed. In terms of the three Cs of color management, the calibration or starting condition must not be altered. After a monitor profile has been created, for example, the user should not alter the display settings. After a printer profile has been made, if the user changes the paper type in the printer, the profile becomes invalid and must be re-made. In the case of digital photography the lighting during capture of the test chart and subsequent capture of scene images must remain constant, but how is this possible in real life situations? The scene illumination is constantly changing, because of this there is no way to make and use an ICC profile, in the traditional sense, for a digital camera.

When profiling any device it is necessary to consider the type of material used for the test chart. In a scanner we choose a chart that is representative of the material we are going to be scanning, such as a transparency chart for transparency material and a paper-based target for a photographic print. This situation breaks down for a digital camera, as it is difficult to have a test chart that has a response that approximates objects in the real world.

There are charts available for digital photography, such as the ColorChecker® Digital SG, where SG stands for semi-gloss, Figure 6.4a or ColorChecker Passport 6.4b. Test charts are useful in digital photography not for profile creation, but as a visual reference for color adjustments and corrections, and color grading in video editing.

In summary, simply extending the profiling process from scanners to digital cameras, copying the same profiling process and tools, is not going to work for the reasons just described. There is a completely different, and much simpler approach needed, when managing color for a digital camera.

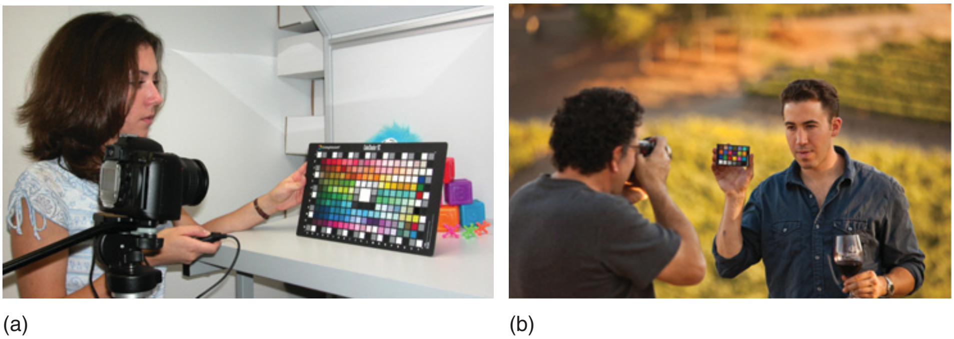

(a) (b)

Figure 6.4 Color charts in digital photography should not be used for profiling, be can be used to assist in color corrections and edits. Image (a) *Source:* Courtesy of Rich Adams. Image (b) *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

6.4 Color Management for a Digital Camera

In order to understand digital camera color management, it is necessary to understand how an image is formed by a camera sensor and how that sensor data is processed to create the final digital image. In this section we consider a digital camera's CCD image sensor and then describe two options for color management – a fully-processed, ready to use, JPEG image, or an unprocessed RAW file.

6.4.1 Bayer Color Filter Array

At the heart of a digital camera is a CCD (Charge-Coupled Device) sensor that consists of red, green and blue filters, called a color filter array, overlaid on a two-dimensional sensor array, Figure 6.5. Each pixel of the underlying sensor array is covered with either a red, green, or blue filter, representing the fundamental method of RGB additive color synthesis.

Different manufacturers may choose a different arrangement and configuration for the color filter array. One of the most commonly used arrangements is the Bayer pattern,

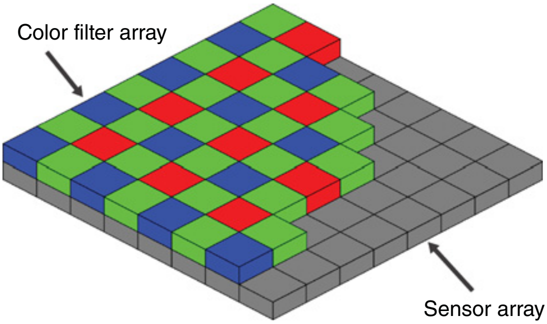


Figure 6.5 A digital camera CCD sensor consists of a color filter array placed over a sensor array. The raw data must be "descrambled" before it is ready to use. *Source:* Colin Burnett, https://en.wikipedia.org/wiki/Color_filter_array#/media/File:Bayer_pattern_on_sensor.svg. Licensed under CC BY-SA 3.0.

due to Bryce Bayer from Eastman Kodak who filed a patent on the process in 1975. The Bayer color filter array contains double the number of green filter elements compared to red and blue, to mimic the response of the human eye – we are more sensitive to green – so more green filters are used to increase the efficacy of image capture.

The image from a CCD sensor has information about the scene, but it is not directly usable as some of the pixels represent red values, many represent green, and some represent blue. The separate red, green and blue sub-images must be processed to create a normal looking image.

The recovery of an RGB image from raw sensor data requires mathematical manipulations commonly referred as color *de-mosaicing* algorithms. In addition to de-mosaicing, there are other processing steps in a camera color processing pipeline. Manufacturers typically employ a number of camera correction operations, such as exposure adjustment, dark noise correction, flare compensation, white balance and color rendering processes, including tone mapping, gamut mapping, and preferred color appearance modeling.

6.4.2 In-Camera JPEG Processing

A digital camera can be set to complete the previously mentioned processing steps, “in-camera,” and produce a processed and image-ready, JPEG file, Figure 6.6. In a JPEG workflow, raw sensor data is processed by vendor-specific, in-camera algorithms and is provided as a fully-processed, ready to use, JPEG image with an associated RGB color space profile.

Each manufacturer knows the configuration and color of the red, green and blue filters of their color filter array and incorporates this information into the color processing pipeline. The color filter array information, camera correction operations, color rendering processes, and the chosen RGB color space profile work together to define the colorimetry of an image from a digital camera. The RGB color space profile ensures

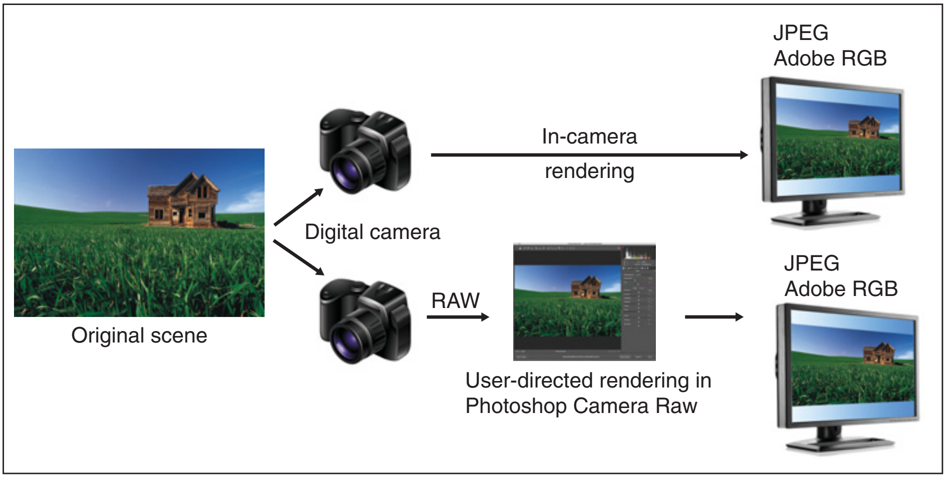


Figure 6.6 There are two main workflows in digital photography – shooting directly to JPEG with in-camera rendering or shooting to RAW and post-processing via software such as Photoshop’s Camera Raw.

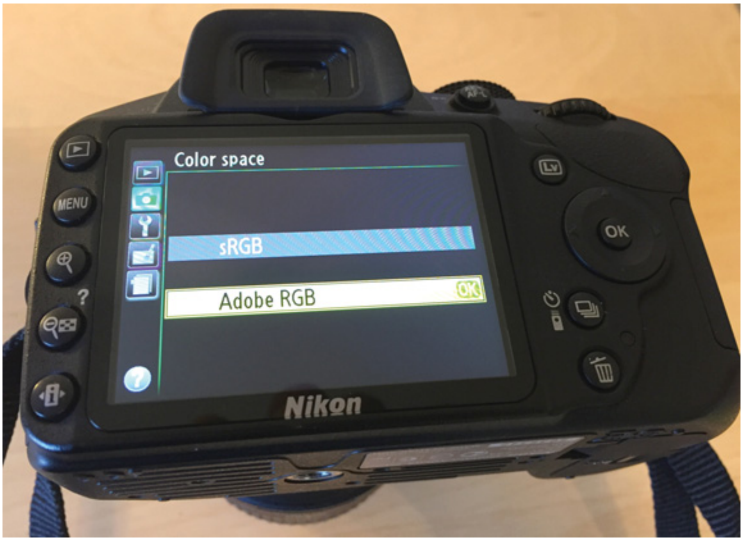


Figure 6.7 For JPEG workflows, the RGB color space profile can be selected within the camera, the Nikon D3200 allows the user to choose between sRGB or Adobe RGB.

correct communication of the image colors to all subsequent processes. The RGB color space profile is associated with the digital camera image and should accompany the image to correctly communicate the colorimetry of the image in all subsequent color managed processes including display on different monitors, web page publishing, printing, etc.

It is important to note that a custom ICC camera profile is not used in this process, however the custom color characteristics of each camera model and CCD sensor are incorporated into the colorimetry of the final image.

If using a JPEG workflow where the camera is allowed to do all the processing steps the RGB color space profile is chosen via a dialog on the camera back, such as shown in Figure 6.7, for the Nikon D3200 digital SLR. The camera offers the choice of an sRGB or Adobe RGB profile. *The selected profile is the source profile for images from this digital camera.*

It is relevant to note that all JPEG images are not created equal, and that each manufacturer will use their own proprietary rendering to create what they think is a pleasing rendition of the scene. In the much the same way that photographers in the past have favored the look and feel of Kodachrome or Fujichrome film for the way those film types rendered the image, in the same way, an Adobe RGB JPEG image from a Nikon or Canon digital camera will render the scene in a vendor-specific way.

6.4.3 Camera RAW Processing

Another popular workflow option in digital photography is a camera RAW workflow, shown as the lower path in Figure 6.6. RAW files evolved because professional users wanted more control over the creation and look of the final image. Rather than allow the camera to internally process and render the pixel values, the idea of the RAW format is to allow the photographer to control the process and modify and refine the look of the image. We can think of RAW processing as analogous to developing and printing a photographic negative. Just as you can generate multiple prints from a single film negative, you can create multiple, different images from an original RAW file. Just as you may store your film negatives indefinitely, so that you can always go back to the source, you may want to archive your RAW files for future re-processing. RAW files are partially processed and need to undergo further color correction and post-processing before they are ready to be viewed and used as a normal image.

The RAW format allows photographers to interpret and custom adjust the image rather than having the camera make pre-determined generic adjustments and conversions. A RAW file allows artistic control for the photographer. The photographer can precisely adjust a range of parameters, including white balance, tone mapping, noise reduction, sharpening, and others, to achieve a desired look. RAW files are widely used by photographers who seek some flexibility in the camera processing pipeline, perhaps the photographer would like to create a sequence of images with the same look and feel. RAW processing provides the ability to easily change your mind, such as choosing a different color balance than you originally used when taking the shot.

An issue with shooting RAW is the number of images you can fit on a memory card, as RAW files can be quite large, and RAW files are proprietary to each manufacturer so there may also be a concern about the longevity of the RAW file format.

Many digital cameras can provide both JPEG and RAW images at the same time. And as part of iOS 10, Apple includes RAW capture and photo editing, allowing iPhones and iPads to capture a pair of images – a compressed format such as JPEG and a RAW format.

It is suggested that if you are confident of the correct exposure, white balance, and other camera settings, then a high quality JPEG file will give you an image that is as good as a RAW file. It is recommended that you shoot RAW when you seek more control over the image colors or expect to need to do some post-processing.

6.4.4 Camera RAW Color Management

What is the correct color management procedure for RAW images? The main components of color management for a RAW workflow are shown in Figure 6.8, here we seek to open an image from a Nikon D3200 digital camera that is in Nikon's proprietary RAW file format – NEF. The figure shows Photoshop's Camera Raw dialog. (In earlier versions of Photoshop, Camera Raw was a plug-in, today it is an integrated part of the program and is launched automatically whenever a RAW file is opened.)

In Figure 6.8 we see a "Camera Profile" described on the right hand side of the graphic. The Camera Profile – despite the name – is not an ICC profile, and in this text we call this a "camera RAW profile," to distinguish it from an ICC color profile. The camera RAW profile in this context relates to the internal color rendering and processing of the RAW file. The camera RAW profile is indicative of the fact that the final image presented to the user incorporates considerable color processing, and if the user finds a color processing scheme that they like, they can store and retrieve it by name.

In the middle of Figure 6.8 we see a list of RGB color space profiles. The way to color manage an image in this workflow, is to process the RAW image and then to associate

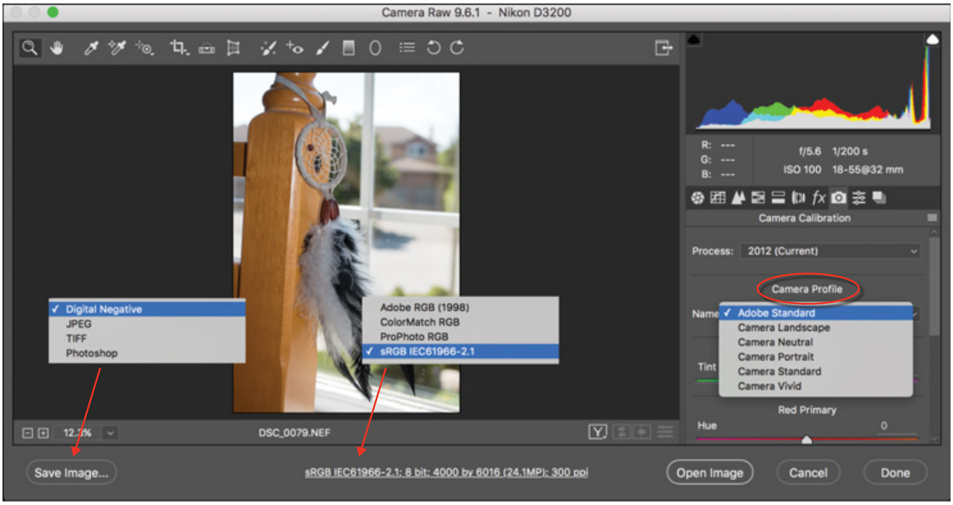
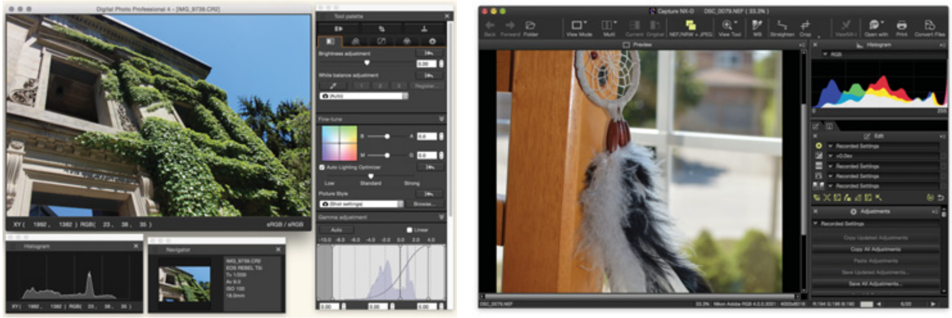

Camera Raw 9.6.1 - Nikon D3200
R: ---
G: ---
B: ---
f/5.6 1/200 s
ISO 100 18-55@32 mm
Camera Calibration
Process: 2012 (Current)
Camera Profile
Name
✓ Adobe Standard
Camera Landscape
Camera Neutral
Camera Portrait
Camera Standard
Camera Vivid
Tint
Red Primary
Hue
0
✓ Digital Negative
JPEG
TIFF
Photoshop
Adobe RGB (1998)
ColorMatch RGB
ProPhoto RGB
✓ sRGB IEC61966-2.1
12.1%
DSC_0079.NEF
Save Image...
sRGB IEC61966-2.1; 8 bit; 4000 by 6016 (24.1MP); 300 ppi
Open Image
Cancel
Done

Figure 6.8 In Photoshop's Camera Raw dialog, (from right to left) we open a Nikon NEF RAW file and apply color processing called "Camera Profile," then convert the image pixel values into a standardized color space such as sRGB with an associated ICC profile, and finally save the image in a finished file format, such as JPEG, TIFF, etc.

with the image, an RGB color space profile from this list. The RAW file is processed with color rendering and other considerations (optionally stored as a camera RAW profile) and finally converted into the selected RGB color space. The color space profile can be chosen by the user, and may be, for example, Adobe RGB or ColorMatch RGB, ProPhoto RGB, or sRGB. The chosen ICC profile can be any RGB profile, but would normally be one of the standard RGB color space profiles as these profiles are well-behaved, have a realistic gamut, are readily available, in other words they are "tried and tested." Commonly used RGB color space profiles are Adobe RGB or ProPhoto RGB, due to their large color gamut. sRGB is also a common option as many web based, smartphone, and tablet applications assume that an image is in the sRGB color space. *The RGB color space ICC profile that is associated with this image represents the source ICC profile for this digital camera image.*

We see in Figure 6.8, bottom left, options for saving the image in different file formats. Photoshop is offering to open the NEF RAW file and convert it to the Digital Negative file format which is a generic file format for RAW files, or a JPEG or TIFF or Photoshop file format. So we see that while both the in-camera and RAW workflows can end up in the same place, the RAW workflow allows the user to manage and change any of the parameters along the way.

Every camera manufacturer offers a RAW processor, such as Canon Digital Photo Professional or Nikon Capture NX-D, Figure 6.9. Third-party programs, such as Adobe Photoshop, Adobe Lightroom, and Apple Photos, are also commonly used to process RAW files, Figure 6.10. It is important to note that each product will apply it's own interpretation and processing and the results may be different when compared to each other and all of them can be different to the vendor's interpretation of the same RAW image file. This may not be a concern for the consumer but it may be critical for professional



(a) (b)

Figure 6.9 RAW files can be processed via the camera manufacturer's software such as (a) Canon Digital Photo Professional or (b) Nikon Capture NX-D.

users. Most photographers will therefore use a single solution, perhaps Adobe Photoshop's Camera Raw or Adobe Lightroom, and stay with a single solution to process their RAW images.

6.4.5 Creating a Camera RAW Profile

A camera RAW profile contains the color rendering instructions used when opening and rendering a RAW digital camera image. A user may like to save their edits as a camera RAW profile, or commercial solutions. Commercial solutions allow the user to create their own RAW rendering that is stored and applied as a "camera RAW profile."

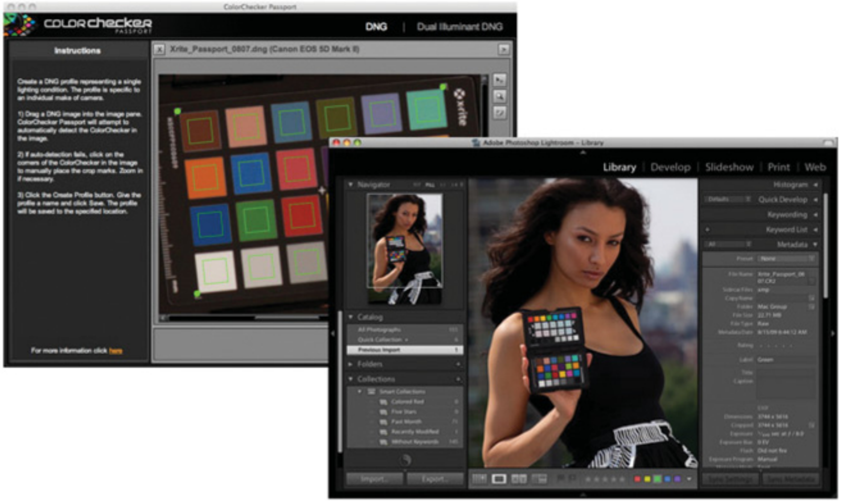
X-Rite ColorChecker Passport is an example of a product that creates a camera RAW profile, Figure 6.11. To create a camera RAW profile, the user takes a picture of a ColorChecker Passport and then imports that into the ColorChecker Passport program for the program to create the profile and save it in a format suitable for Adobe Photoshop or Lightroom.

6.4.6 Digital Negative – DNG

Adobe has proposed a standard, non-proprietary format for RAW files. The format, called Digital Negative or DNG, can be used by a wide range of hardware and software developers and provides a common, standardized RAW file format. Because RAW files are analogous to film negatives in a photography workflow, camera RAW formats are

(a) (b) (c)

Figure 6.10 RAW files can be processed via third party software including (a) Photoshop Camera Raw, (b) Adobe Lightroom, or (c) Apple Photos.


ColorChecker Passport
DNG
Dual Illuminant DNG
Instructions
Xrite_Passport_0807.dng (Canon EOS 5D Mark II)
Adobe Photoshop Lightroom - Library
Library | Develop | Slideshow | Print | Web
Navigator
Catalog
Folders
Collections
Histogram
Quick Develop
Keywording
Keyword List
Metadata
Import...
Export...

Create a DNG profile representing a single lighting condition. The profile is specific to an individual make of camera.

1) Drag a DNG image into the image pane. ColorChecker Passport will attempt to automatically detect the ColorChecker in the image.

2) If auto-detection fails, click on the corners of the ColorChecker in the image to manually place the crop marks. Zoom in if necessary.

3) Click the Create Profile button. Give the profile a name and click Save. The profile will be saved to the specified location.

For more information click here

Figure 6.11 Using X-Rite's ColorChecker Passport test chart and software, it is possible to make a "camera RAW" profile.

often referred to as "digital negatives" and Adobe's file format is therefore called Digital Negative or DNG.

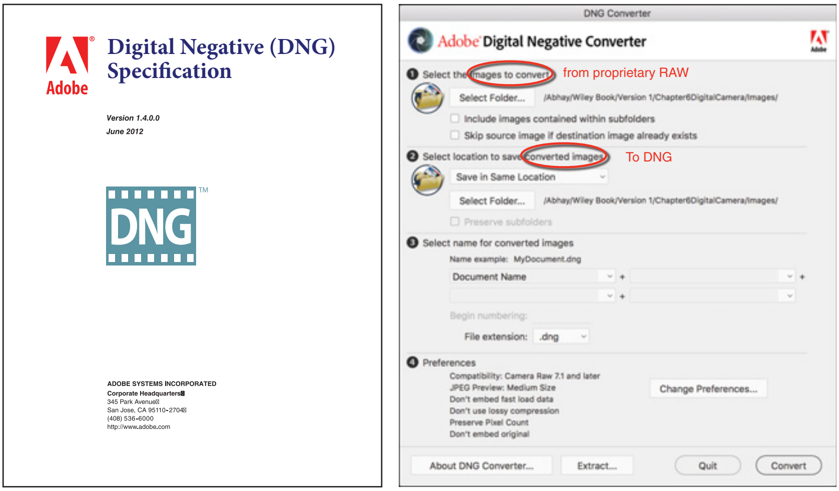
An issue with RAW files is that they are proprietary files, in other words, every camera manufacturer has their own encoding and their own RAW file format. As there is no publicly-documented format for encoding RAW data the structure of RAW files varies from manufacturer to manufacturer, so Nikon's RAW format is not the same as Canon's RAW file. RAW files from Nikon have an extension of .NEF, while Canon cameras use a RAW file called .CR2, etc.

The lack of a standard format for RAW files poses a risk for end users. When a camera model is discontinued, a camera manufacturer may terminate support for the camera's RAW format. This means users have no guarantee they will be able to open archived RAW files in the future. Often a manufacturer will change the format from one camera model to the next, Canon's recent models, for example, use .CR2 RAW files, while older Canon models create files with a .CRW format.

Users may not be able to access images stored in older RAW formats and their images may be lost forever.

The complications caused by different RAW formats is evident in Photoshop's Camera Raw. Photoshop cannot readily open RAW files from every camera model, and Adobe engineers must first study and decipher the file format and then provide support for each camera model individually. We see therefore, that as new camera models are released Photoshop must continuously update their list of supported camera types.

The DNG Specification is a publicly available specification, Figure 6.12a. Anybody can look through this document and can see how a DNG file is arranged with a header pointing to the byte location of the image dimensions or the location of the image pixel data, etc. The DNG Specification is an extension of the TIFF 6.0 format and is compatible with the ISO Standard for TIFF-EP (Tag Image File Format/Electronic Photography).


Digital Negative (DNG) Specification

Version 1.4.0.0
June 2012

ADOBE SYSTEMS INCORPORATED
Corporate Headquarters
345 Park Avenue
San Jose, CA 95110-2704
(408) 536-6000
http://www.adobe.com

DNG Converter

Adobe Digital Negative Converter

1 Select the images to convert
/Abhay/Wiley Book/Version 1/Chapter6DigitalCamera/Images/
☐ Include images contained within subfolders
☐ Skip source image if destination image already exists

2 Select location to save converted images
Save in Same Location
/Abhay/Wiley Book/Version 1/Chapter6DigitalCamera/Images/
☐ Preserve subfolders

3 Select name for converted images
Name example: MyDocument.dng
Document Name +
Begin numbering:
File extension: .dng

4 Preferences
Compatibility: Camera Raw 7.1 and later
JPEG Preview: Medium Size
Don't embed fast load data
Don't use lossy compression
Preserve Pixel Count
Don't embed original

(a) (b)

Figure 6.12 (a) The Digital Negative Specification is publicly available and describes the internal format and structure of a DNG file. (b) To promote the use of the DNG format, Adobe have made available a free Digital Negative Converter utility that translates proprietary RAW files into DNG RAW files.

DNG is designed to accommodate all the information stored in a manufacturer-specific RAW file, thus no manufacturer should be inconvenienced by this specification.

To promote the use of the DNG format, Adobe has made available a free program called the Digital Negative Converter, Figure 6.12b. The DNG Converter allows a user to decode a manufacturer's RAW file and convert that to the standardized DNG file format. Users can convert their Nikon or Canon RAW files into DNG files and use DNG as a future-proof, safe format for storing images. A DNG file can optionally also embed the full original RAW file, for added security. Apple and Android have chosen the Digital Negative (DNG) format as the native format for their camera capture systems.

In the past, Adobe has been generous with sharing file specifications with the user community. The ever popular PDF format for printing, started life as Adobe's Portable Document Format (PDF), and was a proprietary format controlled by Adobe until it was officially released as an open standard in 2008, and published as ISO 32000. Now everybody is free to make, use, sell, and distribute PDF documents. Adobe is expected to do likewise with DNG.

The DNG specification should not be feared, if the format becomes widely accepted Adobe is unlikely to restrict its usage among the photographic community. In summary, Adobe hopes that camera companies will adopt this format and encode their RAW images in DNG format, thus ensuring that presently and into the future, everybody can read and write, RAW images.

6.5 File Formats for Digital Cameras

File formats such as JPEG, commonly used in digital photography, affect image sharpness which plays a role in our perception of color. TIFF files can use lossless image compression and are always safe to use as no colors are changed during opening and saving of the image. We briefly review JPEG (lossy) and TIFF (lossless) file formats as used in digital photography.

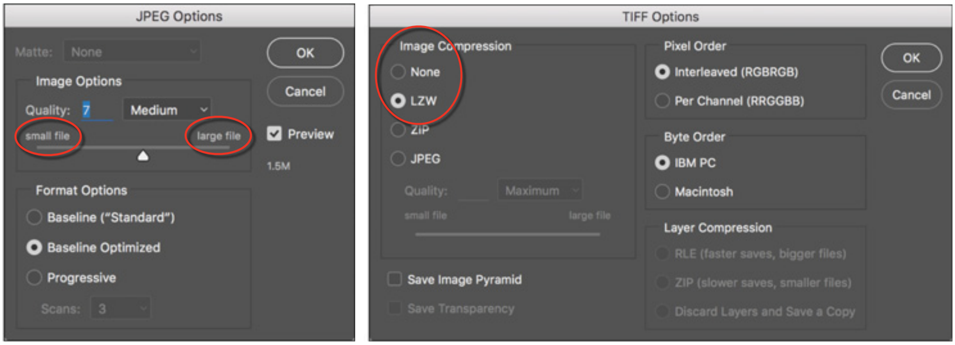
6.5.1 JPEG Lossy File Format

Digital camera images are commonly JPEG compressed. JPEG (Joint Photographic Experts Group) is a compression standard for images and is also a file format. Without compression the file size of an image can be quite large; JPEG compression provides a very effective way of reducing the file size. A smaller file size allows more images to be stored on the camera's media, thus allowing users to capture more images in the field. An image is compressed during picture taking and during storage, and the image can be uncompressed to view it in Photoshop or other image viewer.

The amount of JPEG compression can be described by a ratio, in this context 10 : 1 refers to the original image size vs. the compressed image size. JPEG achieves compression ratios of 10 : 1 without any perceivable loss of quality and with some sacrifice in quality can achieve up to 50 : 1 compression ratios, depending on the image content. JPEG compression works by throwing away some image information, and is therefore called a "lossy" compression method as an image "loses" some information. The photographer can use a slider to direct how they would like the image compressed, a small file is created by throwing away a lot of information, so small file = low quality, while a large file size retains more information, so that a large file = higher quality, Figure 6.13a.

JPEG is very efficient and very useful, however, over-compression can lead to artifacts and image degradation, as shown in Figure 6.14. Artifacts of 8 × 8 pixel blocks are very symptomatic of an image that has been overly JPEG-compressed. The effects of too much JPEG compression are also seen in areas of an image with edges, too much compression produces ringing artifacts around edges as seen in Figure 6.14b.

JPEG is an efficient method of compressing and storing digital camera images, in JPEG compression however, image quality is sacrificed in order to fit a reasonable number of images on a camera media card. Users should be aware of the color implications of JPEG compression due to degradation of image quality at the smaller file sizes.

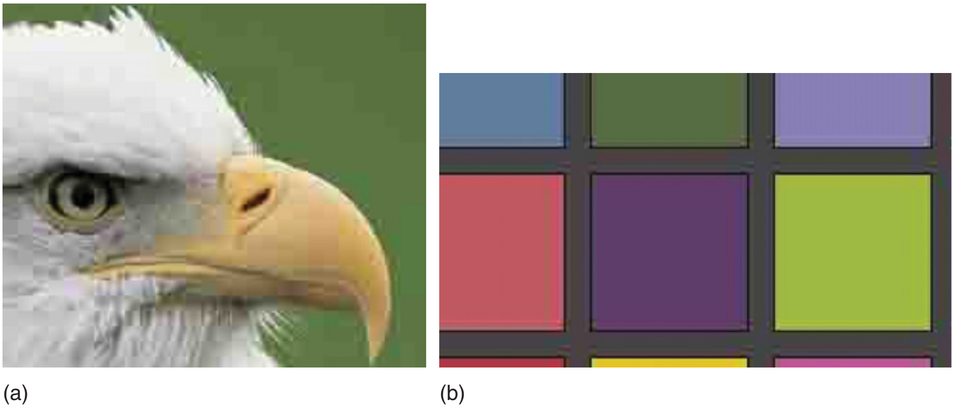


Matte: None
Image Options
Quality: 7 Medium
☑ Preview
1.5M
Format Options
○ Baseline ("Standard")
● Baseline Optimized
○ Progressive
Scans: 3

Image Compression
○ None
● LZW
○ ZIP
○ JPEG
Quality: Maximum
☐ Save Image Pyramid
☐ Save Transparency
Pixel Order
● Interleaved (RGBRGB)
○ Per Channel (RRGGBB)
Byte Order
● IBM PC
○ Macintosh
Layer Compression
○ RLE (faster saves, bigger files)
○ ZIP (slower saves, smaller files)
○ Discard Layers and Save a Copy

(a) (b)

Figure 6.13 (a) JPEG is a lossy compression and file format, there is a trade-off between file size and image quality. (b) TIFF files are always lossless, even when LZW compression is used. Adobe Photoshop Save dialogs are shown here.



(a) (b)

Figure 6.14 (a) Artifacts of 8 × 8 pixel blocks are very symptomatic of an image that has been overly jpeg-compressed. (b) Another tell-tale sign of JPEG compression is ringing artifacts around edges.

6.5.2 TIFF Lossless File Format

TIFF (Tagged Image File Format) images can be saved in compressed or un-compressed modes, Figure 6.13b. It is important to note that the compression method used in TIFF images is lossless, and does not change the image, so TIFF files (compressed or not) are never altered and can be safely used for important image files. In the compressed mode the compression algorithm is called LZW after the inventors – Lempel, Ziv, Welch.

LZW compression is a lossless form of image compression, no information is thrown away. The LZW compression algorithm looks for patterns – areas with repeating pixels, such as the blue sky, and, when it finds many pixels of the same value it makes a shorthand note which serves to reduce the overall file size of the image.

Because of the differences in the compression methods, TIFF images with LZW compression, in general, will not be as small as JPEG images, and we can only expect a 2 : 1 compression ratio, depending on the image content. As the LZW compression method only reduces the file size by 50%, users tend to ignore this option.

The TIFF format never changes the image pixels, images can be saved and re-opened without any loss in image quality, so important images should always be saved in TIFF format.

6.6 Studio Color Management

We have described in this chapter why it is not appropriate to create a custom ICC profile for a digital camera, as in a normal scene there are continuous changes in the lighting conditions.

In the special situation of a studio environment, Figure 6.15, it is possible to create a scanner-like profiling environment. It is possible to use controlled lighting and a test chart that is made of material similar to the object to be photographed, and because it is not an outdoor scene the subject does not have a wide dynamic range. Also we consider that fine art reproduction or catalog and product shots seek a facsimile reproduction of the original. For all these reasons, making a custom profile for a digital

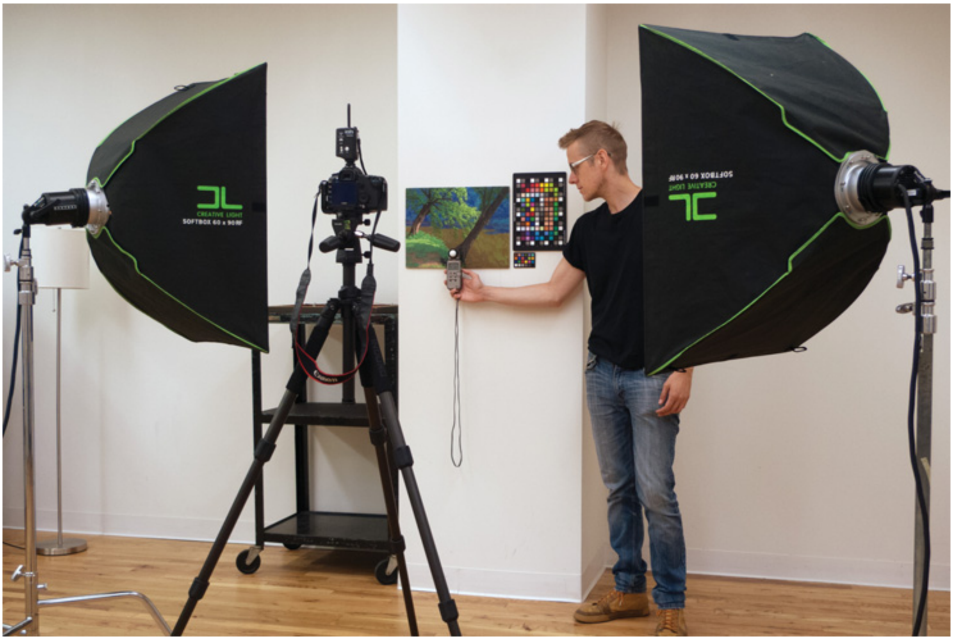


Figure 6.15 In the special case of carefully controlled studio lighting it is possible to use a custom ICC camera profile. Source: Ashe 2014, figure 5.20, p.99.[1] Reproduced with permission of Focal Press.

camera is a viable option and we would employ standard "scanner type" profiling procedures as described at the beginning of this chapter.

6.7 Summary

For many years the photographic community has approached digital camera color management in the same way as scanner profiling. It has now been realized that what worked for scanners is not going to work for digital cameras. In this chapter we described a paradigm shift in the profiling approach between scanners and digital cameras. It was shown that for scanners we seek to create a colorimetric, facsimile reproduction and we do that with a custom profile. By contrast, in a digital camera we seek a pleasing reproduction, and we do that with an RGB color space profile, such as Adobe RGB, or ProPhoto RGB, etc. Color management for digital camera images has been simplified – *to implement color management for a digital camera, the user only needs to associate an RGB color space profile with the final processed image.*

This chapter described a CCD sensor with a red, green and blue color filter array in a Bayer mosaic arrangement. A number of post-processing steps were listed including de-mosaicing, camera corrections, and color rendering processes. These steps must be done before an image is usable. The processing can be done within the camera system to produce a final, ready-to-use, JPEG image.

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[1] Ashe, Tom p., 2014, *Color Manangement & Quality Output: Working with Color from Camera to Display to Print*, New York and London: Focal Press.

The other main workflow available to users, especially those seeking more control, is a RAW workflow. RAW files are unprocessed and must be processed into a final, usable state. An advantage of shooting with RAW means that the photographer can control the color rendering and manually adjust the contrast, white point, color balance, etc. Photographers can complete the RAW rendering process, using the camera manufacturer's own software, such as Canon Digital Photo Professional or Nikon Capture NX-D or third-party software such as Adobe Photoshop's Camera Raw, Adobe Lightroom, or Apple Photos. *Irrespective of a JPEG or RAW workflow, the way to color manage images from a digital camera is to associate an RGB color space profile with the final image.*

In a RAW workflow, the processing steps can be user-defined by a camera RAW profile. It is important to reiterate, that despite the name, a camera RAW profile has nothing to do with ICC profiles, and refers to the underlying color rendering process that is applied during processing of RAW image data. The X-Rite ColorChecker Passport method to create camera RAW profiles was briefly described.

It was shown that camera RAW formats are proprietary file formats that are specific to each camera vendor. Often a camera system may change as new models are introduced. There is a concern that some of the vendor-specific RAW files could be lost forever. Adobe's Digital Negative (DNG) specification was discussed and Digital Negative Converter software was used to convert a proprietary RAW camera file into an open, DNG file format.

Digital cameras capture image data and then save that data in a variety of formats. The two most common formats are JPEG and TIFF. The effects on color of over-compression in JPEGs were demonstrated. TIFF with LZW compression is a lossless compression technique, retaining the full integrity of the original data. TIFF images (with or without compression) are never distorted, there is never any image loss or degradation, which makes TIFF images ideal for important images and images destined for professional use and print.

In this chapter we show that images from a digital camera should enter and travel through a color-managed workflow with an associated profile and that profile should be an RGB color space profile such as Adobe RGB. It is important to associate an ICC profile with a digital camera image. Once an ICC profile has been associated with an image, a photographer can reliably edit and adjust the image colors if needed. If an image is to be printed, the digital camera image with associated profile is sent to a printer, and using a printer profile the RGB values are converted into values that are appropriate for the printer to create the image colors on that printer.

At the end of the day, the actual profile is less important, what is critical is that there is an associated profile and the user knows which one is being used and that this profile is honored and applied at each conversion step within a color-managed workflow.

Color management in digital cameras is a greatly simplified process, and that is the reason that this is one of the shorter chapters in this book!

7

Monitor Profiles

Objectives

- Describe the process of making a profile for a monitor.
- Review commercial monitor profiling software.
- Explain basic parameters such as gamma, color primaries and white point.
- Describe the functionality of the video card lookup table.
- Define procedures for using profiles in web browsers and mobile devices.
- Describe the process and conditions for viewing booths and soft proofing.

7.1 Introduction

A very important part of a color management system is the monitor. If a monitor or laptop image is color accurate we can make decisions based on what we see. A properly configured monitor can be used to evaluate images and perform color-accurate edits and adjustments. If the monitor image is believable, this provides huge savings as designers and photographers can believe the colors they see and prepress operators don't have to create a physical, hard-copy proof.

It is useful to remember that on macOS and most Windows systems the monitor profile is always in use – every image, every menu, every icon is displayed by writing image data via the currently selected ICC profile. In other words, a profile must be used, there is no way to disable the monitor profile. Given the importance of the monitor profile in everything we do and see on the screen or laptop, it is important to understand how to make and use a monitor profile.

The monitor profiling process follows the concept of the three Cs of color management – calibration, characterization, and conversion. In some systems, as described in this chapter, we show that monitor profiling can combine aspects of calibration and characterization into a single step.

In this chapter we consider different color management solutions that cover a range of market segments. We consider free utilities that are available within the macOS and Windows operating systems. These utilities instruct a user to move on-screen sliders, and from these actions a monitor profile is created without a measuring instrument. More accurate profiles are made by commercial profiling software that relies on measuring instruments, examples considered in this chapter include basICColor display,

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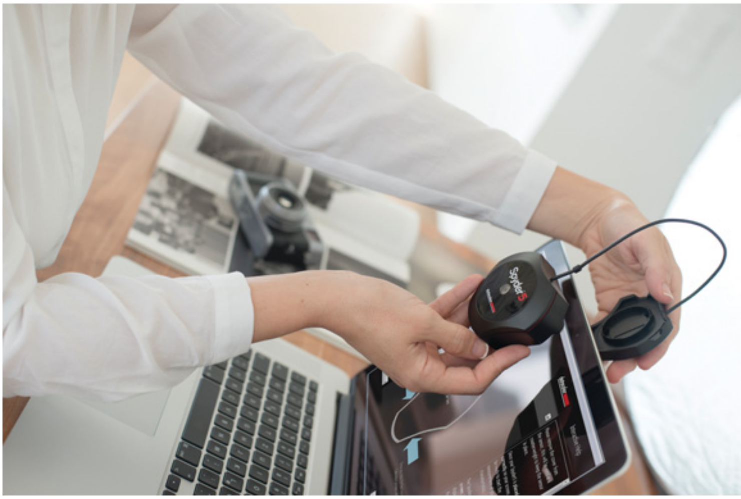


Figure 7.1 A Datacolor Spyder5 colorimeter can be hung over a laptop to create a monitor profile. *Source:* Datacolor. Reproduced with permission of Datacolor.

Datacolor Spyder5PRO and X-Rite i1Profiler. We also consider integrated soft-proofing solutions such as ICS Remote Director and hardware-calibrated monitor systems from EIZO and BenQ.

To profile a monitor you place a measuring instrument on your display and wait while software displays a number of color patches, Figure 7.1. From the measurement of these patches the software determines the gamma, color of your primaries, white point of your monitor, etc. All these parameters are populated and saved in an ICC profile. This chapter provides an explanation of what these parameters mean, and how to set them correctly.

With the increase in Internet-based viewing of images and commercial uses, such as online shopping, it becomes important for web browsers to accurately represent image colors. Here we consider how color-savvy the Firefox and Safari browsers are. In general we see that sRGB has emerged as the default color space for images and graphics destined for web browsers and mobile devices.

In this chapter we consider ISO 3664 and ISO 12646, which are standards that relate to viewing booths and soft proofing respectively. These standards relate to the appropriate viewing booth conditions, luminance levels, and other considerations for press and prepress soft proofing.

Developments in display technology have rendered cathode-ray tube (CRT) monitors obsolete. Now all users will use liquid-crystal display (LCD) devices. LCD displays are flicker free and sharper, which can prevent eye fatigue; they are generally brighter and more stable. LCD displays, however, have a very narrow viewing angle. When using an LCD for color appraisal, the user should therefore always be perpendicular to the display.

Monitor profiles as specified by the ICC do not distinguish between CRTs and LCDs, or laptop, desktop or tablet devices. Users can continue to apply all of the concepts described in this chapter to deal with any older CRTs they may still have in their facility. Most users will have migrated to an LCD device as the LCDs' brightness and stability make them ideal for the color-critical work of professional photography, design, prepress, and press-side proofing.

7.2 Three Cs of Monitor Profiling

Just like other types of profiling, monitor profiling involves the three Cs – calibration, characterization, and conversion.

Calibration is the process of setting a device into a known condition. For a monitor this involves identifying the specific monitor you seek to profile and also involves setting the brightness and contrast on a flat-panel display or laptop. Setting these external parameters is like selecting the printer make and model and paper for an inkjet printer – after these have been selected and set, they must not be changed during subsequent characterization and conversion.

Characterization is the process of understanding the color characteristics of a monitor and creating a profile within which to store that information. A profile would normally store much of the information described in this chapter, that is, gamma, chromaticity of the primaries, white point, etc.

Normally, characterization is a “passive” process in which we simply record within a profile the color characteristics of the device in its current state. In monitor profiling, however, we often change the underlying calibration, for example, we may alter a monitor’s white point and gamma to some required (standard) setting. Perhaps we wish to match a viewing booth and wish to change our display to match a standard such as D50 or D65 or, we seek to establish a gamma setting of 1.8 or 2.2. Profiling software can be used to adjust the response of the monitor to a new calibrated condition, and then characterize the monitor by saving information regarding this new calibration in an ICC profile.

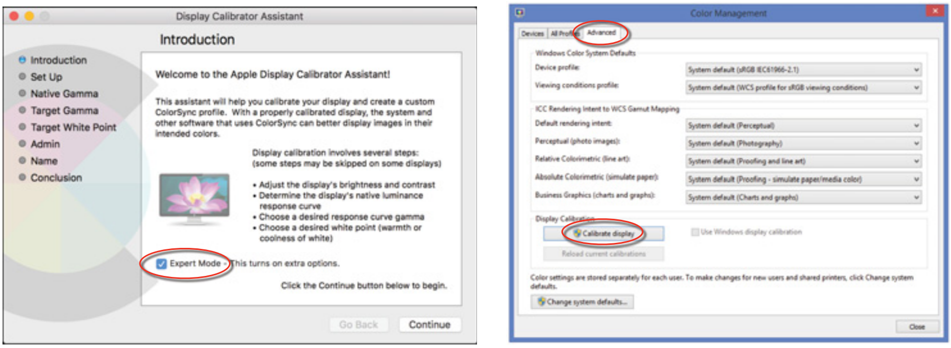
The *conversion* process occurs when we use a profile, in practice this is often in conjunction with the operating system. A monitor profile communicates the characteristics of the device to the operating system and thereby to application software. All images sent to a primary or secondary display are processed via the ICC profile that is currently selected or registered with the system. Essentially the user need take no special action as the monitor profile is used and applied to anything being sent to the display.

7.3 Monitor Profiling Solutions

There are different approaches to controlling color on your display. We first consider making a monitor profile with free macOS and Windows operating system utilities. Next we consider commercial stand-alone profiling software. Some users may consider an “integrated” soft proofing solution, and we describe, as an example, the ICS Remote Director soft proofing solution. Finally, high-end users may consider a flat-panel display with built-in hardware calibration from vendors such as EIZO or BenQ.

7.3.1 Free Utilities

To make a monitor profile you can use a pre-installed, free profiling utility, either Display Calibrator Assistant in the macOS System Preferences, or Display Calibration via the



Welcome to the Apple Display Calibrator Assistant!

This assistant will help you calibrate your display and create a custom ColorSync profile. With a properly calibrated display, the system and other software that uses ColorSync can better display images in their intended colors.

Display calibration involves several steps:
(some steps may be skipped on some displays)

- Adjust the display's brightness and contrast
- Determine the display's native luminance response curve
- Choose a desired response curve gamma
- Choose a desired white point (warmth or coolness of white)

☑ Expert Mode - This turns on extra options.

Click the Continue button below to begin.

Windows Color System Defaults

Device profile: System default (sRGB IEC61966-2.1)
Viewing conditions profile: System default (WCS profile for sRGB viewing conditions)

ICC Rendering Intent to WCS Gamut Mapping

Default rendering intent: System default (Perceptual)
Perceptual (photo images): System default (Photography)
Relative Colorimetric (line art): System default (Proofing and line art)
Absolute Colorimetric (simulate paper): System default (Proofing - simulate paper/media color)
Business Graphics (charts and graphs): System default (Charts and graphs)

Display Calibration

☐ Use Windows display calibration

Color settings are stored separately for each user. To make changes for new users and shared printers, click Change system defaults.

(a) (b)

Figure 7.2 Free monitor calibration utilities are available within (a) the macOS System Preferences, use alt/option to enable the Expert mode, and, (b) in the Advanced tab of a Windows Color Management dialog.

Color Management Control Panel in Windows, Figure 7.2. (On macOS, the Expert mode is hidden as default, use keyboard shortcut alt/option to access the Expert Mode which turns on additional options.)

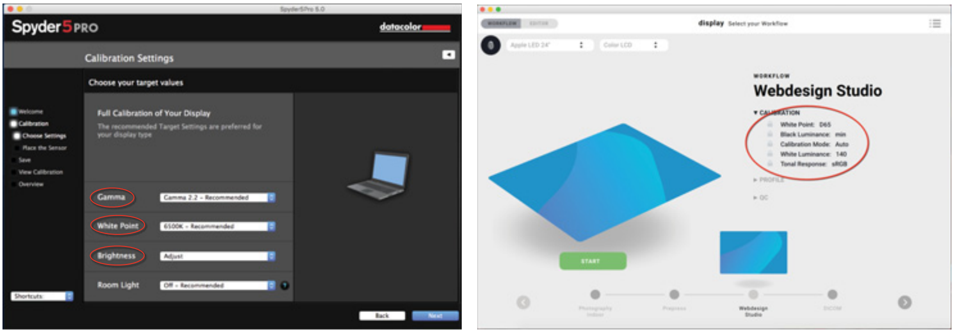
The macOS Display Calibrator Assistant and the Windows Display Calibration utility do not support measuring instruments. Instead, they rely on the user to make visual adjustments using sliders and radio buttons, and from these adjustments the software estimates the required values from which to populate and create a valid ICC profile. This subjective approach is prone to error because it is difficult to gauge the optimum position of the sliders, and different users could arrive at different results. In fact, even the same user could make different choices at different times. Due to the poor accuracy of these utilities they are unlikely to be used in professional-level workflows.

It is useful to note that the free utilities consider the same parameters as commercial color profiling software. The free utilities, for example, incorporate gamma and white point, they just don't have a way to measure these parameters accurately.

7.3.2 Commercial Profiling Software

Anybody serious about color management will use commercial software and hardware to profile their monitors. Commercial software often provides a comprehensive interface, user guidance and will support a range of colorimeters or spectrophotometers. Designers and photographers seeking to only make monitor profiles can find products that are intended only for monitor profiling, such as Datacolor Spyder5PRO, Figure 7.3a. Some software will make all types of profiles, and these solutions often have a module for monitor profiling, such as basICColor Display, Figure 7.3b.

Colorimeter-based monitor profiling is very affordable, for example, X-Rite's ColorMunki Smile or Datacolor's Spyder5EXPRESS are available for around $100 – and this price includes the colorimeter! Using these types of solutions, it is feasible for designers, digital photographers and videographers to conduct professional-quality monitor calibration at a reasonable price.


Spyder5PRO
datacolor
Calibration Settings
Welcome
Calibration
Choose Settings
Place the Sensor
Save
View Calibration
Overview
Shortcuts
Back
Next
display
Select your Workflow
WORKFLOW
EDITOR
Apple LED 24"
Color LCD
START
PROFILE
QC
Photography indoor
Prepress
Webdesign Studio
DICOM

Choose your target values

Full Calibration of Your Display

The recommended Target Settings are preferred for your display type

Gamma: Gamma 2.2 – Recommended
White Point: 6500K – Recommended
Brightness: Adjust
Room Light: Off – Recommended

WORKFLOW

Webdesign Studio

CALIBRATION
White Point: D65
Black Luminance: min
Calibration Mode: Auto
White Luminance: 140
Tonal Response: sRGB

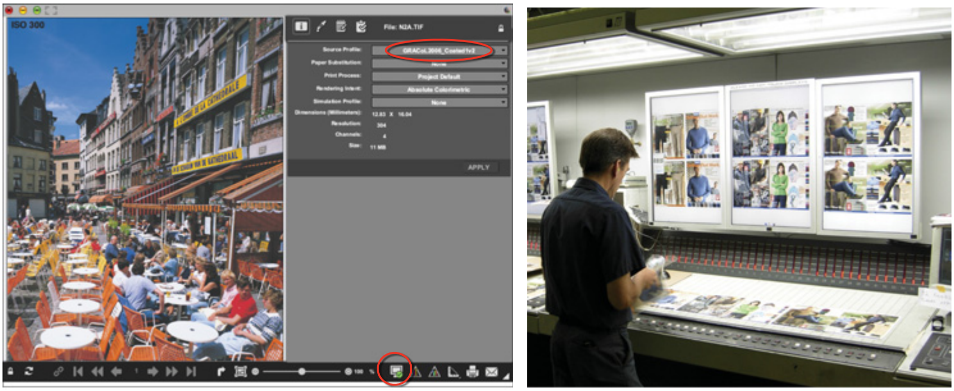
(a) (b)

Figure 7.3 During monitor profiling, programs reference similar items – gamma, white point and brightness. (a) Datacolor's Sypder5Pro (b) basICColor display 6.

7.3.3 Integrated Soft Proofing Solutions

ICS Remote Director is an example of a soft proofing solution that bundles together the profiling software, measuring instrument hardware, and then creates a color managed environment that applies press profiles to allow display, evaluation, annotation and collaboration of real-time color managed proofs, Figure 7.4a. The system knows and warns if any of the participants collaborating on a proof mark-up are using a calibrated system or not, and this information is shared with all other participants as shown in the figure. Files are uploaded to a server and are remotely available to designers, prepress or press operators who can access images and confirm colors for press-side checking, Figure 7.4b.

In addition to ICS Remote Director, integrated solutions are available from a range of other suppliers, including, for example, Dalim DIALOGUE, HELIOS PrintPreview, Kodak MATCHPRINT Virtual, ORIS Color Tuner // Web, etc.


ISO 300
APPLY

File: N2A.TIF
Source Profile: GRACoL2006_Coated1v2
Paper Substitution: None
Print Process: Project Default
Rendering Intent: Absolute Colorimetric
Simulation Profile: None
Dimensions (Millimeters): 12.83 X 16.04
Resolution: 304
Channels: 4
Size: 11 MB

(a) (b)

Figure 7.4 (a) ICS Remote Director is an integrated solution that allows creation of press proofs. The monitor calibration status of each participant is displayed. (b) Press operators can adjust ink keys and match a press sheet to a monitor soft proof.

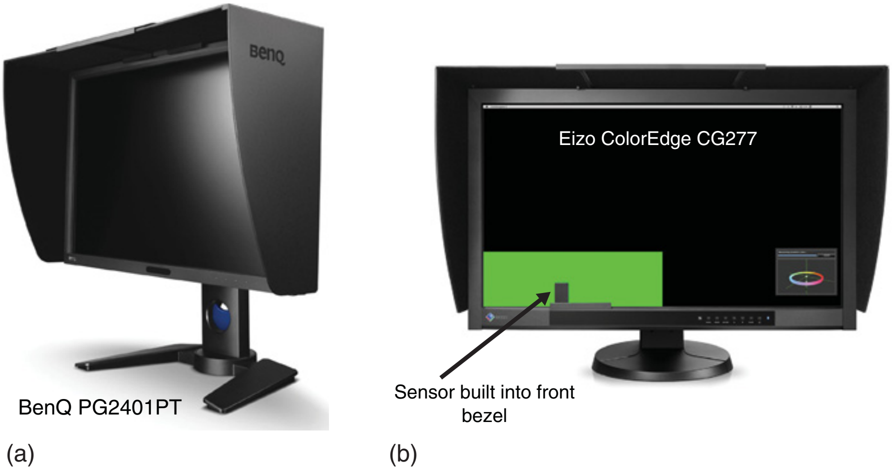


Figure 7.5 Professional displays such as the (a) BenQ Pro Graphics series, and (b) the EIZO ColorEdge series both offer hardware calibration. Image (a) *Source:* BenQ. Reproduced with permission of BenQ Corporation. Image (b) *Source:* EIZO. Reproduced with permission of EIZO Corporation.

7.3.4 Hardware Calibrated Monitor Systems

Color management users would be wise to consider high-end, professional systems such as the BenQ Pro Graphics series of displays or the EIZO ColorEdge series, that offer hardware calibration, Figure 7.5.

What is “hardware calibration”? During monitor profiling, we often create a change to the device’s behavior. Often we seek to adjust the response of the monitor from its native characteristics to some standard condition. Typically we may seek to create a D50 white point and 2.2 gamma. In the solutions described so far, the change is implemented via software; i.e. a color lookup table is used to change the monitor’s white point and gamma to the required setting.

High-end systems, such as BenQ and EIZO, adjust their white point in a more fundamental way. These displays change the parameters of the video amplifiers inside the display. This alters the relative balance of the LCD driver, which represents a change in the way the device is working. This is called “hardware calibration.” The big advantage of a hardware calibrated monitor is that it can achieve the correct white point without much loss in brightness. This issue is explained in more detail in Section 7.4.6.

As a result of hardware calibration, these types of monitors require their own specialized software. EIZO ColorEdge monitors are therefore bundled with EIZO Color-Navigator color management software, while BenQ’s software is called Palette Master Element.

EIZO ColorEdge monitors incorporate another feature where the sensor is housed within the front bezel, Figure 7.5. The sensor swings up, onto the screen when needed for color characterization.

Once a monitor profile is made for a hardware-calibrated monitor, all other aspects of the color management workflow remain the same.

7.4 Monitor Basics

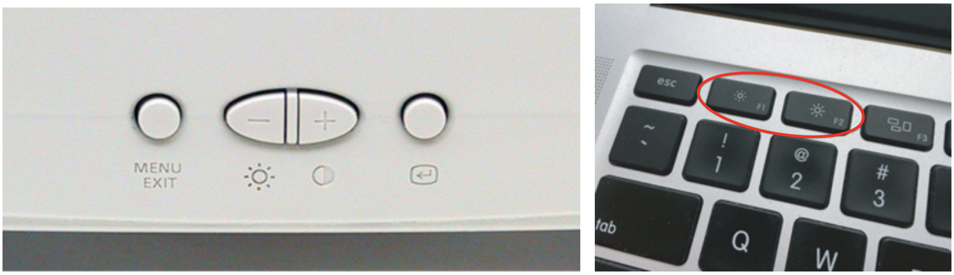
There are some basic settings associated with monitor profiling. There is adjustment of the monitor *brightness* and *contrast*, via the front panel of a display or keys on a laptop. During subsequent monitor profiling we consider a number of the display's characteristics. The parameters measured and stored during profiling are the *color of red, green, and blue screen primaries, contrast or gamma of the monitor, and white point of the monitor.* Though sometimes called different things by different manufacturers, all profiling software takes into account these basic attributes, Figure 7.3. These settings are generally not well understood, so here we present an explanation of what the basic monitor settings refer to and how to set them correctly.

7.4.1 External Brightness and Contrast

Brightness and contrast are controlled via the front panel of a monitor or keys on a laptop keyboard, Figure 7.6. Brightness and contrast are part of the calibration process so no information relating to the brightness and contrast setting is directly stored within a monitor profile. The profile is built "on top of" any brightness and contrast settings and the user is left with the responsibility of not changing these settings. The first thing to do in monitor profiling is to set these levels correctly, and then continue to the actual profiling process.

What are the correct settings for brightness and contrast? Consider first the brightness control. This can be set too bright or too dark. In both cases, the effect is most pronounced at the lower end of the grayscale, as indicated in Figure 7.7a. If the monitor is too bright, the darkest part of an image will not show a real dense black. The overall effect is that the image will lack contrast and appear flat and washed out. On the other hand, setting the monitor too dark causes the shadows to fill in, and thus shadow detail is lost.

The ideal brightness setting is to retain a distinction between all levels as we go from dark to light. The brightness should be set to just achieve this look. A good guideline for the correct level of black is that the black within the screen should match the bezel – the black surround that borders the active part of the screen.



(a) (b)

Figure 7.6 During monitor profiling, the first step is to adjust the brightness and contrast controls on (a) the front of a monitor or (b) on a laptop keyboard.

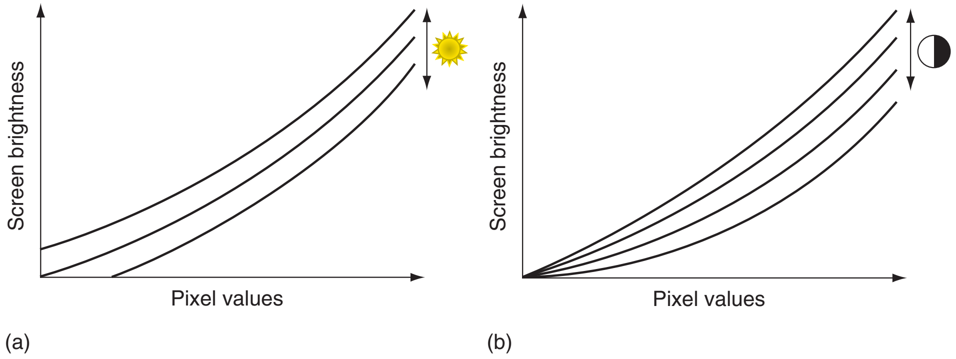


Figure 7.7 (a) The brightness setting primarily affects the shadows, either removing dense shadows or creating blocked in shadows (b) The contrast setting primarily affects the image highlights.

After the brightness is set, the contrast can be adjusted. This control is not that critical and to a certain extent, can be set according to personal preference. The main effect of changing the contrast is to change the overall brightness of the image, Figure 7.7b). The contrast primarily affects the lighter parts of the image. In general, the contrast can be altered so that it produces a reasonably bright result in ambient lighting. Do not increase the contrast too much, or the screen will become too bright, which causes reflections and flare.

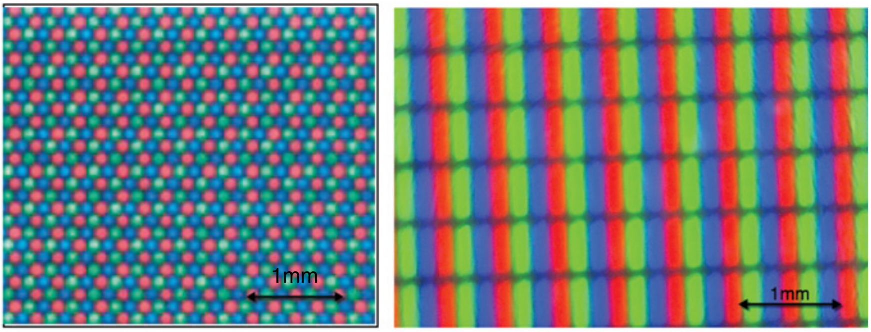
It is important to set the brightness and contrast so that they produce a pleasing range of continuous tones without losing detail due to blocked-in shadows or blown-out highlights. There are a number of gradient type test images to help with these settings. Once we know what we are trying to achieve, i.e. the brightness and contrast we are aiming for, it makes finding the correct level a bit easier.

7.4.2 RGB Primaries

After the brightness and contrast have been set, profiling can begin and the profiling program takes over and measures the characteristics of a monitor. Consider the red, green and blue primaries. Profiling software will use an instrument to measure the color of the display's primary elements. An older CRT-type monitor displays images using red, green, and blue phosphor dots, an example of which is shown in Figure 7.8a. Electrons are emitted from guns at the back of the monitor and are accelerated toward the front panel. At the front, the electrons strike the phosphor dots, making them glow and thereby producing light. From normal viewing distances the dots merge to form a continuous image.

An LCD panel consists of a backlight that shines through tiny, liquid crystals and then through red, green and blue filters, Figure 7.8b. From normal viewing distances the color filters are not visible and merge to create a continuous image.

The "color" of the primaries (phosphor dots or LCD filters) can vary from monitor to monitor and from manufacturer to manufacturer. Suppose the same RGB pixel values are sent to two monitors. The color we see will be slightly different between the two, even when they display the same pixel value. If we know beforehand what "color" the primaries are, we can compensate for any differences. For example, we can alter the



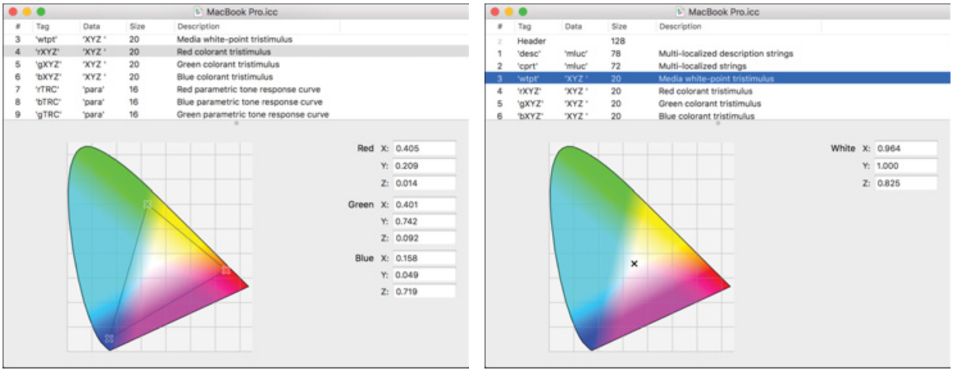
(a) (b)

Figure 7.8 (a) CRT monitors created color using red, green, and blue phosphor dots. (b) Today, LCD panels use a backlight and RGB filter elements.

instructions sent to a monitor so that when an image is viewed, the color will be the same. As all monitor primaries are slightly different, by measuring them and storing that information in an ICC profile we can make adjustments to the pixel data that is being sent to the display, and thus allow for differences that exist between displays.

During profiling, a measuring instrument will measure the color of the red primary, the color of the green primary, and the color of the blue primary. To do this, the red, green, and blue groups are turned on by sending to the monitor RGB pixel values of (255, 0, 0), (0, 255, 0), and (0, 0, 255), respectively. If you ever watch the whole monitor profiling sequence, you will see that included in the colors displayed on the screen during measurement will be full red, green and blue.

The chromaticity (color value) of the red, green, and blue primaries is measured in terms of XYZ and stored in a profile in the rXYZ, gXYZ, and bXYZ tags. If you look at these tags, you can see the values for the primaries, an example of which is shown in Figure 7.9a. In an additive system (monitors) all colors realizable by the display are contained within the gamut triangle formed by connecting the red, green, and blue primary



#	Tag	Data	Size	Description
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'rXYZ'	'XYZ '	20	Red colorant tristimulus
5	'gXYZ'	'XYZ '	20	Green colorant tristimulus
6	'bXYZ'	'XYZ '	20	Blue colorant tristimulus
7	'rTRC'	'para'	16	Red parametric tone response curve
8	'bTRC'	'para'	16	Blue parametric tone response curve
9	'gTRC'	'para'	16	Green parametric tone response curve

Red X: 0.405
Y: 0.209
Z: 0.014
Green X: 0.401
Y: 0.742
Z: 0.092
Blue X: 0.158
Y: 0.049
Z: 0.719

#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'mluc'	78	Multi-localized description strings
2	'cprt'	'mluc'	72	Multi-localized strings
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'rXYZ'	'XYZ '	20	Red colorant tristimulus
5	'gXYZ'	'XYZ '	20	Green colorant tristimulus
6	'bXYZ'	'XYZ '	20	Blue colorant tristimulus

White X: 0.964
Y: 1.000
Z: 0.825

(a) (b)

Figure 7.9 (a) Screen elements are measured during the profiling process and their XYZ values are stored in a monitor profile. (b) During profiling the white point of the monitor is also measured and stored.

coordinates, so this triangle in the Yxy diagram represents the achievable gamut of the display, based on real measurements.

7.4.3 White Point

In a computer display, RGB values of 255, 255, 255 make a "white" pixel. But what color is this white? Is it a warm, reddish white or a blue white? In the same way that the color of a light source affects objects viewed in that light, similarly the white point of a monitor affects the color rendition of images displayed in that environment. When setting up a monitor, it is important to determine and record the "color" of the white point.

During monitor calibration you can ask the system to give you a D50, or any other white point. The profiling process alters lookup tables to create the requested white point. During the profiling process, the altered white point of the monitor is stored in the profile, Figure 7.9b. The white point of the monitor is recorded as an XYZ value in the white point tag (wtpt).

In all monitor software you can choose the white point to be anything from D50, used in prepress and proofing, to illuminant A. If you are trying to compare your screen image with a print viewed under D50, the white point of the monitor should be set to D50. For the graphic arts, the white point tends to be D50 or D65. Both of these white points are "middle of the road" and are good choices for a white point setting – especially if you need to compare the results with a viewing booth.

7.4.4 Monitor Gamma

The gamma number for a computer monitor tells us about the contrast setting for the monitor and therefore the appearance of images displayed on the monitor. If the gamma of a monitor is too low, images will appear very flat, as in Figure 7.10a, whereas a high gamma setting may cause a harsh transition from light to dark Figure 7.10(c). Note that there is a loss of shadow detail and the cobblestones disappear in the image displayed with a simulated high gamma.

All monitors come from the factory with an inherent gamma of between 2.0 and 3.0. Lookup tables can be used to change this basic setting. Traditionally, on macOS, it was

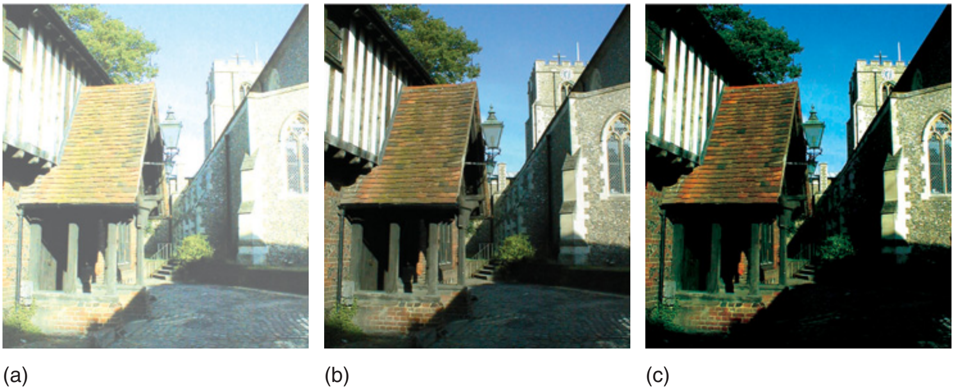

(a) (b) (c)

Figure 7.10 The gamma setting of a monitor creates a (a) flat, (b) normal, or (c) a high-contrast image.

customary to set the gamma to 1.8, whereas on the PC the standard tends to be 2.2. A smaller gamma number decreases the contrast and lightens the image, and a higher number will increase the contrast and darken the image. The commonly used sRGB profile contains a gamma setting of 2.2.

During monitor profiling, the software calculates the gamma of your display. This tag is called the TRC (tone reproduction curve) and was described in Chapter 5, Inside Profiles. It is possible to have different gamma values for each of the red, green, and blue channels, and thus a monitor profile contains three tags: rTRC, gTRC, and bTRC. In most cases the same gamma value is stored in all three channels.

In general, it is less important to have a particular gamma value (1.8, 2.0, 2.2, etc.); it is more important that the gamma behavior of your monitor is accurately represented by the value in the TRC curve of your monitor profile.

7.4.5 Luminance Levels

An aspect of a display that is measured during profiling is the luminance level. Luminance refers to the amount of light the monitor emits. Luminance is not directly related to color but it can affect our perception of color. In a workroom of monitors it is often desirable to have the light output of the screens match so that operators can look at an image on any device and perceive the same colors. Some profiling vendors help you in setting all your monitors to the same luminance – keeping in mind that to do this, all monitors must be set to the dimmest monitor in the group.

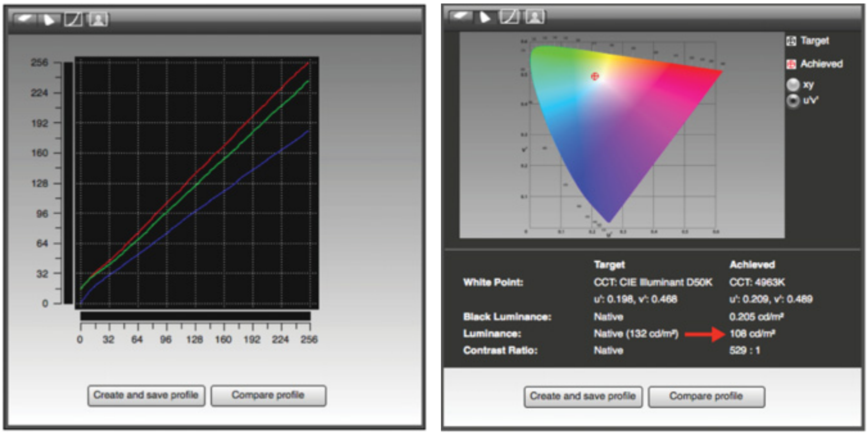
Matching the luminance levels is an issue that applies to viewing booths. When you compare two images, they should be viewed in light levels that match. To get an image on the screen to match a proof in a viewing booth, the light levels should be similar. In practice, viewing booths can be very bright, and monitors struggle to create an image with similar luminance levels.

Currently, light levels do not have to be explicitly considered or noted in a monitor profile. Most profile makers, however, do report the luminance level to the user, in candelas per square meter (cd/m^2). A target, very good monitor luminance would be 160 cd/m^2.

Changing the color temperature of your display can dramatically reduce its luminance. If your monitor is uncalibrated, it probably looks bright and blue. Working at a monitor's native white point allows for a higher luminance level which is generally more comfortable for most users and does not require a darkened room. If you calibrate a display and ask for a D50 white point, the new white point is obtained but in doing so the luminance level is reduced.

7.4.6 The Dingy Yellow Effect

Why does a profiled monitor appear dark and yellow? If your monitor is uncalibrated, it probably looks bright and blue, and has a native color temperature of around 9000 K. If you make a monitor profile and ask for a D50 white point you will typically get a display that looks very dull and yellow. In changing the native white point to the requested white point, the luminance output of the monitor is reduced, creating a dingy, yellow appearance, typical of a D50-profiled monitor. Why does this happen and what are the workarounds?



	Target	Achieved
White Point:	CCT: CIE Illuminant D50K	CCT: 4963K
	u': 0.198, v': 0.468	u': 0.209, v': 0.489
Black Luminance:	Native	0.205 cd/m²
Luminance:	Native (132 cd/m²) →	108 cd/m²
Contrast Ratio:	Native	529 : 1

(a) (b)

Figure 7.11 (a) To change a monitor's native color temperature to D50, lookup tables are used to reduce the output of the green and blue signals, which makes the monitor appear warmer. (b) The correct color temperature is achieved but the monitor's luminance is reduced.

In the default state, monitors make white by operating with all three primaries full on. Thus full red, green and blue primaries appear as white. If you have not previously performed monitor calibration, your monitor is nice and bright and probably quite bluish with a color temperature of around 9000 K. Suppose during monitor calibration you ask the system to give you a D50 white point. D50 is much "redder" than the native white point, and thus to create a D50 response, you need to add more red to the display. However, the system is already working at maximum output, and there is no way to add more red, but we can obtain the same effect by turning down the green and blue output. The way to do this is via a color lookup table that is stored in an ICC profile using a tag called the video card gamma tag (vcgt), Figure 7.11a.

Computer systems display images using a video card. The video card contains the color lookup table. The color lookup table can be changed by profiling software. When a profile is selected, the color lookup table from the vcgt tag is downloaded to the video card which alters the display's characteristics.

Figure 7.11a shows the lookup table in a profile that has been adjusted to create a D50 white point. The lookup table axis are input and output red, green and blue pixel values, with a scale on both axes of 0 to 255. At the top end of the graph you will see that the red output is unchanged, but the output of the green channel is reduced and the blue output is reduced even further. When this lookup table is actioned, it will alter pixel values on their way to the display, and the "color" of a white pixel will now be much warmer then before, in this instance creating a near-D50 response from a 9000 K monitor.

The new white point is achieved by reducing the output of the green and blue primaries, which reduces the monitor's luminance and results in the well-recognized dingy, yellow appearance typical of a D50-profiled monitor. Figure 7.11b shows that the luminance has dropped from 132 to 108 cd/m^2. At low light levels, we tend to see white as yellow, which further compounds the issue. Usually chromatic adaptation comes to the rescue, and after a few moments the dull yellow appearance will disappear as we adapt to the new white point of the scene.

In general, there is no requirement to use D50 or D65 to achieve a color managed display. All that is needed for a color accurate display is an ICC profile that accurately represents the display's color characteristics. Working with a profiled monitor, but at a monitor's native white point, allows for a higher luminance level which is generally more comfortable for most users, and it does not require a darkened room. (But comparison with a print in a viewing booth does require matching the color temperature.)

The video card lookup table can alter the display white point as described here, and in practice it may also alter the display's gamma, for example, to reduce an inherent gamma of 2.5 to a requested gamma of 2.2. So the video card lookup table serves a dual-purpose and can be used to simultaneously alter the monitor's white point and gamma.

Next time you are making a monitor profile consider the options at the end of the profiling sequence. After measuring the inherent, native gamma and white point, applications will allow you to change and request any white point and gamma. Depending on what you ask for, the program calculates a lookup table that will create the new values. The new gamma and white point values represent the monitor's color characteristics and are stored in appropriate monitor profile tags for use during color conversion.

Proof of the video card lookup table construct can be seen at the start of the monitor profiling process. As a monitor profiling process begins the screen will flicker, this is where the software is clearing any video card lookup table contents and resetting the lookup tables to a linear response. Another proof for the existence of the lookup tables is when different monitor profiles are selected in the operating system. As different profiles are selected, their vcgt tag contents are instantaneously downloaded to the video card and the screen flashes to reflect these changes.

7.5 Making a Monitor Profile

Let us now consider some practical aspects of monitor profiling. The following are some helpful tips to follow when you profile your monitor.

- Set the bit depth of your monitor to a setting you want to use when looking at images. Normally this will be 24 bits (also known as "millions") of color or more.
- Set the spatial resolution to the resolution you would like to use, e.g. retina display.
- Make sure your monitor has been turned on for 20–30 minutes. This gives it sufficient time to warm up and stabilize. During this period make sure the screen saver is disabled.
- Delete or disable competing profiling programs. Monitor profiling programs try to control the display via the video card, and it is important to have only one program operational at a time. If any program has a startup utility that is used at boot time, this should be deleted.
- Clean the face of the monitor to remove fingerprints and dust.
- Set up the room in the way you want to use it after profiling. The position of the monitor in relation to windows and ambient lighting are important. Room lighting can make an enormous difference to the appearance of the screen image. Some profiling systems will measure room lighting.

- Set the background pattern on your desktop to be a neutral gray. Busy or bright patterns can interfere with color judgment.
- It is easy to profile a secondary monitor, all profiling software and operating systems support dual monitors and can assign different profiles to the primary and secondary display.
- Profile making in any of the commercial programs involves following the on screen instructions. The user is required to help with the first part of the process – that is, the brightness and contrast setting – after which the software takes over and automatically displays and measures a number of samples.
- Once you have made a monitor profile, make sure it is saved in the correct place. Profiling software will normally do this for you. On macOS and Windows there is often the system and local user folders.
- Before you get too carried away with viewing and manipulating images, you should always check that the system is using the monitor profile you want it to use. On macOS X, go to System Preferences/Displays and ensure that your profile is selected.
- Monitor performance changes and declines over time. Re-characterize your monitor every month or so.
- Consider the error report presented at the end of the profiling process, this alerts you to the gamut ability of your monitor or any potential problems that may have occurred during the profiling process.

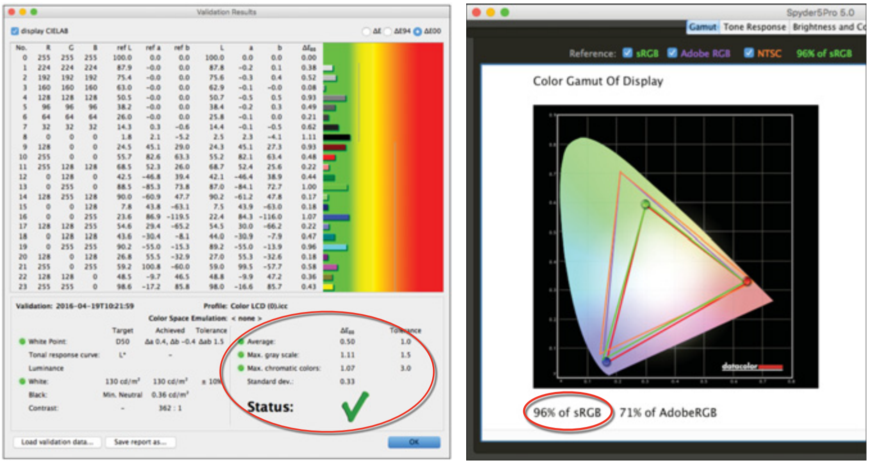
7.6 Checking a Monitor Profile

Often users on a budget will ask – can I use my monitor for color managed work? Is it possible to profile my monitor? For a display to be used for color management (i) you need an ICC profile that is an accurate representation of the color characteristics of the device and (ii) the device should have a reasonable color gamut. Here is how you can answer these two questions.

At the end of the monitor profiling process, most profiling software will offer to verify the profile you just made. Given you have the measuring instrument already connected for the profiling process, it is a good idea to spend a few extra minutes to run the verification routine. The verification routine uses fewer patches and does not take long, and provides valuable feedback and reassurance that everything is working as intended.

To check a profile, the profiling software will run through a test routine, displaying colors and measuring them. The process measures and verifies the gamma, the chromaticity of the primaries, white point of the display, and also the overall colorimetry (color conversion process). The basICColor display software provides a ΔE value and tick mark that indicates whether the profile accurately describes the monitor's characteristics or not, Figure 7.12a.

A display cannot accurately reproduce colors that are out of gamut. A profile may provide an accurate representation of the device, and achieve a tick mark in terms of accuracy, but if the device gamut is too small, this limits the usefulness of the display. Datacolor's Sypder5Pro verification process provides an easy to understand graphic and dialog that shows, for example, a MacBook Pro laptop can achieve 96% of the sRGB gamut, 7.12b, indicating that the MacBook Pro would be adequate for correct appraisal of any imagery destined for workflows that assume sRGB, such as Internet browsers and mobile phones and tablets.



☑ display CIELAB

No.	R	G	B	ref L	ref a	ref b	L	a	b	ΔE_{00}
0	255	255	255	100.0	0.0	0.0	100.0	0.0	0.0	0.00
1	224	224	224	87.9	-0.0	0.0	87.8	-0.2	0.1	0.38
2	192	192	192	75.4	-0.0	0.0	75.6	-0.3	0.4	0.52
3	160	160	160	63.0	-0.0	0.0	62.9	-0.1	-0.0	0.08
4	128	128	128	50.5	-0.0	0.0	50.7	-0.5	0.5	0.93
5	96	96	96	38.2	-0.0	0.0	38.4	-0.2	0.3	0.49
6	64	64	64	26.0	-0.0	0.0	25.8	-0.1	0.0	0.21
7	32	32	32	14.3	0.3	-0.6	14.4	-0.1	-0.5	0.62
8	0	0	0	1.8	2.1	-5.2	2.5	2.3	-4.1	1.11
9	128	0	0	24.5	45.1	29.0	24.3	45.1	27.3	0.93
10	255	0	0	55.7	82.6	63.3	55.2	82.1	63.4	0.48
11	255	128	128	68.5	52.3	26.0	68.7	52.4	25.6	0.22
12	0	128	0	42.5	-46.8	39.4	42.1	-46.4	38.9	0.44
13	0	255	0	88.5	-85.3	73.8	87.0	-84.1	72.7	1.00
14	128	255	128	90.0	-60.9	47.7	90.2	-61.2	47.8	0.17
15	0	0	128	7.8	43.8	-63.1	7.5	43.9	-63.0	0.18
16	0	0	255	23.6	86.9	-119.5	22.4	84.3	-116.0	1.07
17	128	128	255	54.6	29.4	-65.2	54.5	30.0	-66.2	0.22
18	0	128	128	43.6	-30.4	-8.1	44.0	-30.9	-7.9	0.47
19	0	255	255	90.2	-55.0	-15.3	89.2	-55.0	-13.9	0.96
20	128	0	128	26.8	55.5	-32.9	27.0	55.3	-32.6	0.18
21	255	0	255	59.2	100.8	-60.0	59.0	99.5	-57.7	0.58
22	128	128	0	48.5	-9.7	46.5	48.8	-9.9	47.2	0.36
23	255	255	0	98.6	-17.2	85.8	98.0	-16.6	85.7	0.43

Validation: 2016-04-19T10:21:59

Profile: Color LCD (0).icc

Color Space Emulation: < none >

	Target	Achieved	Tolerance
● White Point:	D50	Δa 0.4, Δb -0.4	Δab 1.5
Tonal response curve:	L*	-	
Luminance			
● White:	130 cd/m²	130 cd/m²	± 10%
Black:	Min. Neutral	0.36 cd/m²	
Contrast:	-	362 : 1	

	ΔE_{00}	Tolerance
● Average:	0.50	1.0
● Max. gray scale:	1.11	1.5
● Max. chromatic colors:	1.07	3.0
Standard dev.:	0.33	

Status: ✓

Reference: ☑ sRGB ☑ Adobe RGB ☑ NTSC 96% of sRGB

96% of sRGB 71% of AdobeRGB

(a) (b)

Figure 7.12 (a) basICColorDisplay checks a display profile and offers a green tick mark. (b) Spyder5PRO expresses the display's gamut as a 96% percentage of sRGB.

In ICC v2 monitor profiles, there was little ability to deal with out-of-gamut colors in monitor profiles. As profiling software introduces profiles that are made in accordance with the current revision of the ICC specification (Version 4), it is likely that we will see the ability to deal with gamut differences of the display. Photoshop has an option that can perform "pretend" monitor gamut mapping, as discussed in Chapter 11, Color Management in Photoshop.

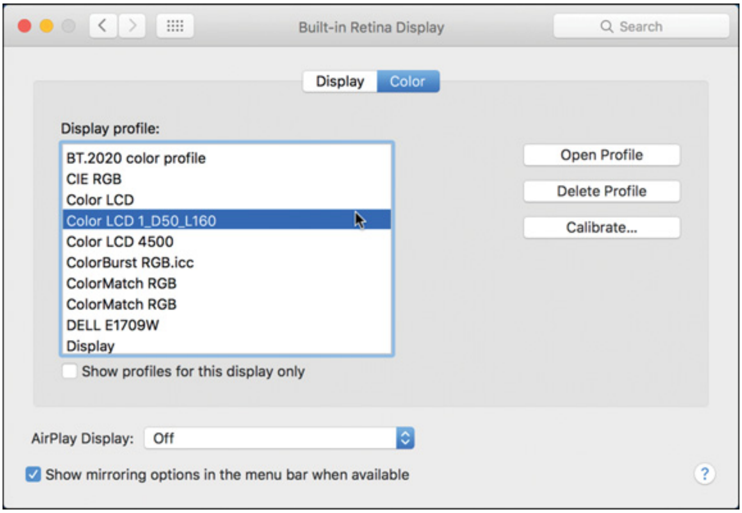
7.7 Monitor Profiles and Windows

We have seen in this chapter that a monitor profile is used in conjunction with the contents of the color lookup table in the video card. Although the concept of a video card lookup table is common to both macOS and Windows platforms, only macOS has a well-specified system for storing and using it. There is widespread debate about the use of the video card gamma tag (vcgt). Part of the problem is that the tag is specified by Apple ColorSync and not by the International Color Consortium (ICC). In fact the vcgt tag is not even mentioned in the current ICC Specification.

In theory, downloading the lookup table contents to the video card, should be as simple as selecting a monitor profile. Whenever a profile is selected, the contents of the vcgt tag should be downloaded to the lookup table in the video card, Figure 7.13. This does happen on macOS where the screen will flicker and change as you select different monitor profiles.

The vcgt tag is not a required tag, so some vendors generate a vcgt tag, and some do not. If a profile is chosen that does not contain a vcgt tag, there is the risk that the video card may contain unrelated content. It is suggested therefore, that if a vendor chooses not to implement a vcgt tag, then they should ensure that the lookup table does not contain unrelated content.

The vcgt tag is not always correctly interpreted on PC platforms. Some profiling programs, especially on the PC, download data to the video card at startup time. The



Display profile: Color LCD 1_D50_L160

☐ Show profiles for this display only

AirPlay Display: Off

☑ Show mirroring options in the menu bar when available

Figure 7.13 As you select different monitor profiles in macOS, the contents of the vcgt are downloaded to the video card, thus the screen may flash and change color.

problem with this is that if you change your monitor profile after startup you are using a profile without its corresponding lookup table. To get things "back in sync" on the PC you may need to initiate a manual download of the contents of the vcgt to the video card.

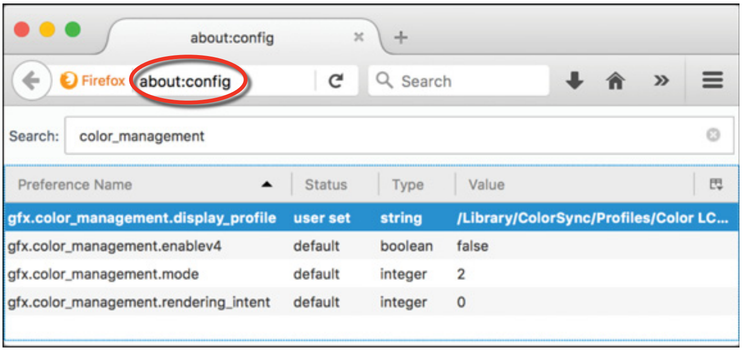
7.8 Monitor Profiles and Web Browsers

With the increase in Internet-based viewing of images and commercial uses such as online retail it becomes important for web browsers to accurately represent image colors. Here we provide a review of the main issues relating to Internet-based color management and consider how color-savvy the main browsers are. In general we see that sRGB has emerged as the default color space for images and graphics destined for web browsers and mobile devices.

In displaying the content of a web page, there are two profiles involved – the source profile, embedded in the image and the destination profile – the monitor profile. For color-accurate display in a web browser, the web browser needs to be color management aware, by this we mean that it should be able to process image data using ICC profiles, and the browser must be able to retrieve information relating to the currently selected monitor profile from the operating system.

There are two main situations to consider, images that contain an embedded profile, and the majority of images that contain no profile, i.e. untagged images.

Consider first the case of web images that contain an embedded profile. If you have an image with an embedded profile then a web browser can open the image and use its profile. In this instance the profiles being used to transform into and out of the profile connection space are the image's embedded profile as the source profile and the monitor profile as the destination profile. Firefox can be configured to use a v2 or v4 ICC profile embedded in an image, Figure 7.14. Firefox is a fully color-managed browser, and its color management strategy is controlled via a configuration panel that is revealed by



Search: color_management

Preference Name	Status	Type	Value
gfx.color_management.display_profile	user set	string	/Library/ColorSync/Profiles/Color LC...
gfx.color_management.enablev4	default	boolean	false
gfx.color_management.mode	default	integer	2
gfx.color_management.rendering_intent	default	integer	0

Figure 7.14 Firefox color management settings are revealed by typing "about:config" in the address bar.

typing "about:config" in the Firefox address bar. Safari is also fully color-managed, as expected from a macOS browser. Safari correctly utilizes an embedded profile when available and then the monitor profile to give a properly color managed rendition of image colors. Safari is fully color managed "out of the box." If you can guarantee that your images are going to be viewed using only Firefox or Safari, and that every user will have accurately profiled their monitor, then you need do nothing else but embed a profile in your images on your web page. This utopian situation rarely exists.

Not all images served to a web page will have an embedded profile. Often web graphics are very small in size to enable higher download speeds and a faster page refresh. Given the small size of the image itself, an ICC profile of equal or greater size is an onerous bandwidth burden. Most of the time web-based images and graphics will therefore have no embedded profile. A web browser must have a strategy to deal with images that contain an embedded ICC profile and a default behavior when an image contains no embedded profile. In accordance with the Internet regulatory body – the World Wide Web Consortium (W3C) – all untagged images and page elements should be considered sRGB by the web browser. *Most web-based imagery will therefore assume a default sRGB source profile.*

As most web images will assume an sRGB profile it is possible to correctly prepare images for Internet viewing. Rather than color manage each image with its own profile it is possible to convert the image into sRGB space. To do this use the embedded profile as the source profile and sRGB as the destination profile. In this way the image is processed to sRGB, and although the sRGB profile will not be explicitly used, the web platform is going to assume an sRGB profile, so that the image will be displayed as intended.

There is often discussion relating to a typical macOS display (gamma of 1.8) vs a typical Windows display (gamma of 2.2). This is now a moot point as sRGB defines a gamma of 2.2.

7.9 Monitor Profiles and Mobile Devices

Images can be viewed on tablets and mobile devices. In the same way that sRGB is the default for browsers, sRGB is also becoming the default color space for images and graphics on mobile devices.

Generally, in this book we have been considering an *active* color management approach, where an image and associated profiles are presented to a CMM and color conversions are applied to every pixel in real time. This type of active color management is well suited when using a desktop, laptop, different displays, and for output to production print or desktop printers and proofers.

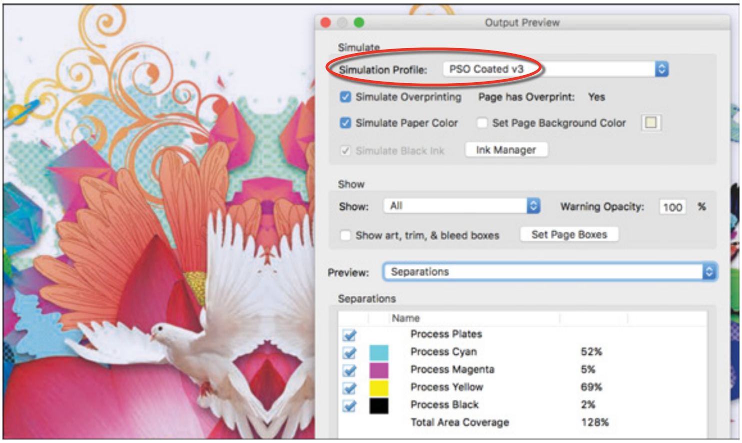
Active color management has considerable overheads in terms of memory, processing power and power consumption, and so in mobile devices (such as Apple iOS) we may use a *targeted* approach in which we pre-process all imagery to a known color space, such as sRGB and do no color processing on the device. In the same way that a web browser does not seek an embedded profile and instead assumes an sRGB color space for all images, content on a smartphone or tablet can assume an sRGB color space.

In the targeted approach, the color conversion to sRGB is not performed dynamically on the iOS device, instead it happens during authoring and image preparation on your desktop. In the previous section we described the steps that could be used to convert to sRGB, the same process would be used to prepare images for a mobile environment.

This type of "targeted" color management is similar to what the video industry has traditionally done in targeting high definition (HD) video, where the source content is transformed to the HD color space, this way, when the content is rendered on HD displays nothing further has to be done. In summary, with targeted color management, the color match occurs at authoring time instead of dynamically at runtime.

7.10 Soft Proofing in Adobe Acrobat

One way of communicating and approving color in documents is to use Adobe Acrobat. A soft proof is created in Adobe Acrobat using *View>Tools>Print Production>Output Preview*, Figure 7.15. The profile depicted here, "PSO Coated v3" (also known as Fogra 51) is being used as the print process to simulate. There is a sequence of profiles being used here. Each image may be RGB or CMYK and have an associated source profile. A simulation profile is used to simulate the reproduction of



Simulation Profile: PSO Coated v3

☑ Simulate Overprinting Page has Overprint: Yes

☑ Simulate Paper Color ☐ Set Page Background Color

☑ Simulate Black Ink

Show: All Warning Opacity: 100 %

☐ Show art, trim, & bleed boxes

Preview: Separations

		Name	
☑		Process Plates	
☑	🟦	Process Cyan	52%
☑	🟪	Process Magenta	5%
☑	🟨	Process Yellow	69%
☑	⬛	Process Black	2%
		Total Area Coverage	128%

Figure 7.15 A soft proof is created in Adobe Acrobat using Output Preview to simulate a press condition.

the image colors on the output process, usually a printing process with reduced color gamut. Finally the image colors are being displayed on the monitor using the currently selected monitor profile.

Compliance to recent PDF/X standards requires specification of the output intent in a PDF file, so customer, creator, print service provider and printer can all visually see and approve the same simulated output colors. We note that "Output Preview," is as the name suggests, only a preview, and we are only simulating the final output colors without any image conversions – which is a good thing.

7.11 Standards for Viewing Booths

The specifications of a viewing booth, and the conditions for side-by-side comparison between a monitor and a proof are prescribed by a number of ISO standards. In this section we consider three related ISO standards:

- ISO 3664 – Graphic Technology and Photography – (Viewing booths)
- ISO 12646 – Graphic Technology – Displays for Colour Proofing (Displays)
- ISO 13655 – Graphic technology – Spectral measurement (Instruments).

Because of the impact of the viewing conditions on perceived color, an industry standard, ISO 3664, has been established for viewing booths. ISO 3664 ensures that the color temperature and intensity of the light is correctly specified and the viewing booth surround is a neutral gray. Commercial viewing booths such as that shown in Figure 7.16 are manufactured in compliance with ISO 3664.

ISO 3664 suggests that a viewing booth should have two light levels, denoted P1 and P2. The level for P1 is 2000 lux, which is a high light level. P1 lighting facilitates critical comparison because it will reveal even the subtlest differences between prints. P2

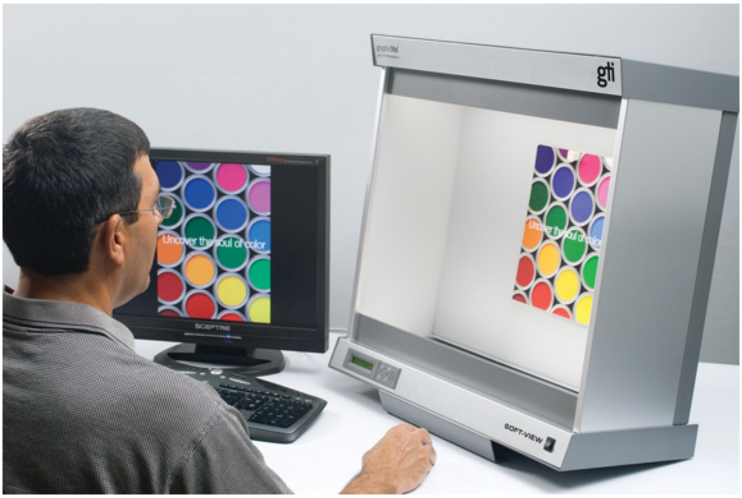


Figure 7.16 In soft proofing, when making color comparisons, light levels between the monitor and the light booth should be similar. A dimmable light booth for soft proofing is the gti SOFV-1xi. *Source:* GTI. Reproduced with permission of GTI.

illumination is specified as 500 lux, which is more representative of average commercial and residential lighting levels. The P2 appraisal level in a light booth, corresponds to a monitor luminance of 160 cd/m^2.

In practice, light booths can be very bright, and monitors struggle to create an image with similar light output. It is useful to have a viewing booth with a dimmer switch so that the booth can be dimmed to match the output of the display. ISO 12646 is a standard that deals with soft proofing, i.e. matching monitor images to prints in a viewing booth.

ISO 13655 is a standard that describes the amount of ultraviolet light in measuring instruments via use of the M1 measurement mode. Via ISO 13655 for measuring instruments and ISO 3664 for viewing booths, emphasis has turned to requiring a closer simulation of D50 (UV-included) illumination in both instruments and viewing booths.

If a company is producing color critical work it is essential that appraisal of color in images be done in a well-controlled environment, such as a dedicated viewing booth. When visiting a commercial printer check to see if they have press-side viewing booths and whether the booths have lamps that meet current ISO standards.

With up-to-date technology – ISO 13655 (M1) measuring instruments, ISO 3664 compliant light booths, and ISO 12646 procedures and practices, it is possible to achieve excellent agreement between the screen and the printed result, enabling soft proofing that generates time and cost savings.

7.12 Summary

We saw in this chapter that profiling software comes in many guises, from simple utilities such as the macOS Display Calibrator Assistant to commercial programs such as basICColor display, Datacolor Spyder5PRO and X-Rite i1Profiler. Usually only commercial solutions are used in professional situations.

Perhaps the biggest challenge to making a monitor profile is knowing how to make adjustments and what settings to choose. A number of monitor settings were described, including brightness and contrast, color of the primaries, white point, gamma and luminance. Knowing what these parameters are and how to set them, allows us to make informed decisions and ensures that we get the most out of our display.

An overriding concept developed in this chapter is that it is important that we build a profile that accurately represents the display and the condition it is in. As long as a profile accurately describes a monitor it can cope with, within reason, any setting you may have chosen – D50, D65, native, gamma of 1.8 or 2.2, etc.

One of the important topics explained in this chapter is the video card lookup table. It was shown that the video card lookup table is an important part of monitor profiles and can be used to alter the display to some user-requested condition, often creating a D50 white point and gamma of 2.2.

sRGB is becoming the default, assumed color space in Internet based imagery with Firefox and Safari web browsers, and also in tablet and mobile devices. In this instance images are previously processed to sRGB and no color management conversion is done at run-time by a web browser or tablet. This framework speeds up web page loading in a browser and reduces power requirements in a smartphone.

The importance of appropriate viewing conditions and ISO 3664-compliant viewing booths was considered. In the context of soft proofing it was shown that the luminance level of the monitor and the print must be similar to achieve a good match between screen and print. If operators can rely on the appearance of their screen image, they can edit and adjust values in the belief that this is what they will get when the job is printed. Soft proofing is one of color management's most powerful tools. When used correctly, it can lead to enormous savings in time and materials.

8

Press and Printer Profiling

Objectives

- Introduce color management for printers, proofers and presses.
- Define different types of profile including custom, generic and process profiles.
- Describe calibration and linearization during printer profiling.
- Explain the G7 calibration method for CMYK systems.
- Describe common printer test charts such as IT8.7/4 and ECI 2002.
- Discuss reference printing conditions such as GRACoL, SWOP, FOGRA, CRPC.
- Describe the process of "printing to the numbers."
- Explain rendering intents for printing applications.
- Describe the use of device link profiles and device link workflows.

8.1 Introduction

This chapter describes the profiles and processes required for color management of print devices. The ICC defines a profile class for output, which encompasses many different types of printing processes. ICC output profiles can be used for desktop devices, inkjet proofers, digital xerographic presses, large format inkjet systems, and commercial printing processes including flexographic, gravure, and offset printing. In terms of an ICC profile, these devices are all treated the same, but in practice we find there are different considerations for each technology type.

This is an extensive chapter because printers, proofers and presses are functionally very different and it is necessary to consider different aspects of color management for each printer category.

Depending on the printing system it is possible to consider making a custom ICC profile, or using a generic profile supplied by the manufacturer, or adopting a standard profile. Each approach, and where and how to use it, is described in this chapter.

In common with all profiling, printer profiling consists of the three Cs. For print processes, *calibrating* the device to get it into a stable, repeatable state is especially important. This chapter describes a number of calibration and linearization techniques for inkjet, digital presses and offset lithographic printing.

A major part of printer profiling involves *characterization* which is done by printing and measuring a test chart. There are an array of charts to choose from, including the

Understanding Color Management, Second Edition. Abhay Sharma.
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IT8.7/4 or the ECI 2002 chart. This chapter explores a number of issues, such as the number of patches on the chart, how to print a chart with "no color management," and how to average chart measurements. After a chart is measured, the next stage in the process is profile generation. During profile generation, there are choices to be made regarding black generation and lookup table size.

Conversion, i.e. application of a profile, can be done in a RIP or application software, such Adobe Photoshop.

In Chapter 1, we described three types of profile – *custom*, *generic* and *standard*. In this chapter we explore in detail the process of making a *custom* printer profile. There is also an extensive section on using a *standard* profile in the form of a reference printing condition. There is a trend towards using generalized press conditions, called reference printing conditions, such as GRACoL, SWOP, and CRPC in North America and FOGRA51 in Europe. It is often impractical to make a custom profile for an offset press, and we find that users are not interested in having a multitude of profiles for each slightly different press condition. This chapter describes the process for using reference printing conditions to manage color in prepress and press workflows.

In conjunction with reference printing conditions is a trend towards managing color using a process called "printing to the numbers." Old fashioned methods of matching a physical proof have been replaced with numerical, measurement-based printing and proofing. Today, color management in all areas of printing and proofing is done "by the numbers" where the numbers refer to L*a*b* values of a chosen reference printing condition.

Normally, a digital camera image has more colors and a larger gamut than most print processes are capable of reproducing. There are usually many colors that are out of gamut of the printing system. Gamut issues are dealt with via rendering intents. This chapter provides an explanation for the four official ICC rendering intents – perceptual, relative colorimetric, absolute colorimetric and saturation.

The chapter ends with a look at a useful profile class called device link profiles and a description for some of the options available for process control in printing.

8.2 The Three Cs in Printer Profiling

Before a device can become part of a color-managed workflow it needs to have a profile. Consider the process for making a custom printer profile consisting of the three Cs of color management – calibration, characterization and conversion. Figure 8.1 provides an overview of the custom printer profiling process. To make a printer profile you need to *calibrate* the device and then *characterize* the device by printing and measuring a test chart and using profiling software to make a profile. A RIP or color workflow or application software such as Photoshop is used to *convert* image data using the profile.

8.3 Calibration in Inkjet Systems

Inkjet systems, such as printers and proofers and large format systems, have a number of calibration steps that are used to create a better behaved printing process on which

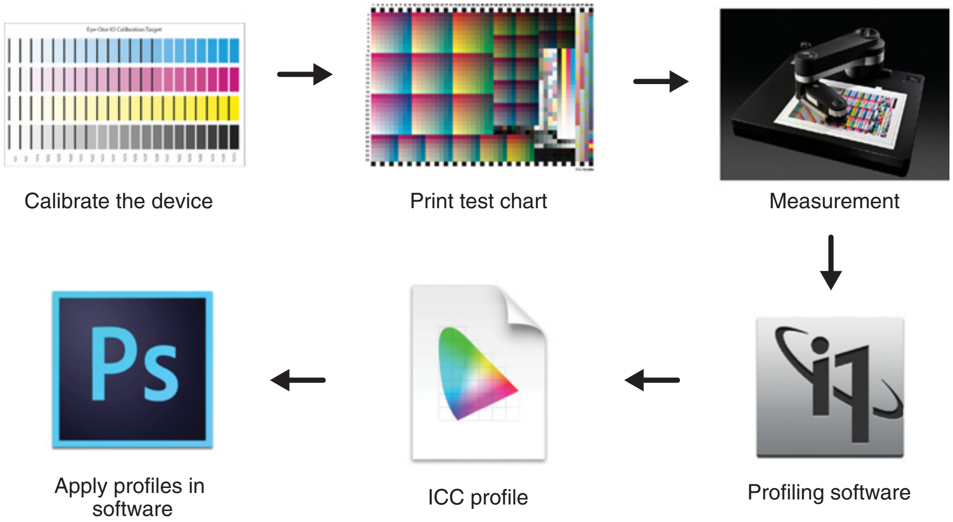


Figure 8.1 To make a printer profile you calibrate your device, print a test chart, measure the test chart, use profiling software to make a profile, and then apply the profile to images in Adobe Photoshop.

to base subsequent color management. In this section we consider ink limiting, ink hooking, and ink splitting.

8.3.1 Ink Limiting

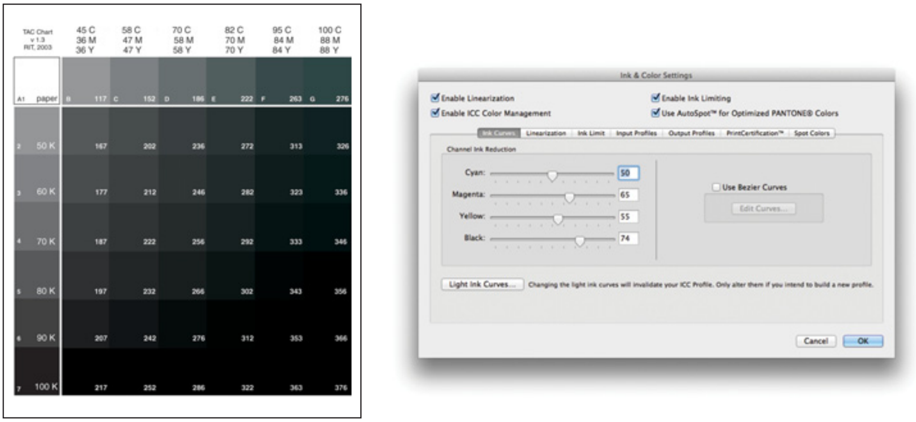
The total area coverage (TAC) or total ink limit (TIL) – is obtained by the addition of C-M-Y-K dot% values, thus the maximum possible value for a CMYK print process is, 100% C + 100% M + 100% Y + 100% K = 400%.

Ink limiting can be applied to all printing systems, and in inkjet printing it serves to reduce the inking level to prevent ink pooling, and cockling of the substrate. *Ink limiting* is applied in the calibration stage for inkjet systems, and reduces the output of the different channels from their maximum output of 100% ink coverage to a lower number, which may be different for each channel, perhaps between 50–80%, depending on the ink and media type.

The media type is one of the primary contributors to how the ink limit should be set. Better quality, coated photo paper, for example, can hold more ink compared to other media types. The print resolution setting (1440 or 2880 dpi) is also a significant factor in determining the ink loading.

An ink coverage target provides a way of determining the optimum total ink coverage for a paper-ink combination, Figure 8.2a. The target shows increasing, different amounts of CMY inks at specified black levels. Typically a user would select a value at which it just becomes difficult to discern a difference between adjacent patches.

After the optimum ink limit setting has been determined, it can be entered into RIP software, an example dialog from ColorBurst is shown in Figure 8.2b.



(a)

TAC Chart v 1.3 RIT, 2003	45 C 36 M 36 Y	58 C 47 M 47 Y	70 C 58 M 58 Y	82 C 70 M 70 Y	95 C 84 M 84 Y	100 C 88 M 88 Y
A1 paper	B 117	C 152	D 186	E 222	F 263	G 276
2 50 K	167	202	236	272	313	326
3 60 K	177	212	246	282	323	336
4 70 K	187	222	256	292	333	346
5 80 K	197	232	266	302	343	356
6 90 K	207	242	276	312	353	366
7 100 K	217	252	286	322	363	376

(b)

Ink & Color Settings

☑ Enable Linearization
☑ Enable Ink Limiting
☑ Enable ICC Color Management
☑ Use AutoSpot™ for Optimized PANTONE® Colors

Channel Ink Reduction

Cyan: 50
Magenta: 65
Yellow: 55
Black: 74

☐ Use Bezier Curves

Changing the light ink curves will invalidate your ICC Profile. Only alter them if you intend to build a new profile.

Figure 8.2 (a) An ink coverage target can be used to determine the optimum total ink coverage. (b) After ink limits have been visually determined, they can be entered into RIP software such as ColorBurst. *Source:* Robert Chung. Reproduced with permission of RIT.

Note that the ink limit setting is part of the calibration process and should not be altered. Changing the ink limit after a profile has been made changes the device behavior and invalidates the printer profile.

8.3.2 Ink Hooking

Inkjet inks exhibit *ink hooking*, where the ink changes hue at higher concentration. To analyze ink hooking, we can measure the L*a*b* values that result from printing and measuring CMYK color ramps, Figure 8.3. In this figure we see that the ramps of color

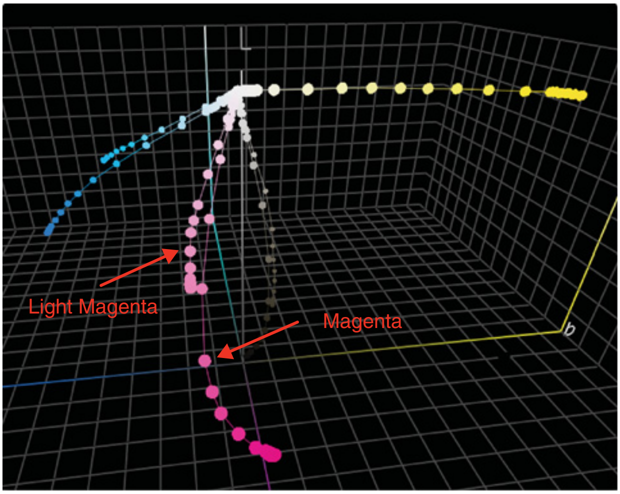


Figure 8.3 In an L*a*b* diagram, the light magenta ink does not increase the extent of the color gamut but is used to create a smoother tonal gradation in the lighter areas of the image. Magenta ink shows ink hooking at higher ink levels.

are linear for some region and then curve and bend at the darker end of the ramps. We see for example that the magenta channel "hooks" round to the right, and becomes more yellow.

Theoretically, if the hooking is part of the measurement data, an ICC profile can accommodate this behavior. In practice however, presenting this type of data to an ICC profiling program may lead to inaccurate results.

It is useful to note that the magenta ramp changes in hue, but it does continue to extend slightly which increases the gamut of the system. This means that reducing the ink limit to curtail the ink hooking can reduce the device's color gamut. A user would need to determine if they wish to limit a color ramp to just the values that create a linear response, or seek the absolute maximum gamut possible and can accept the hooking bad behavior. So we see that there is a trade-off to be had between ink hooking vs. gamut extent.

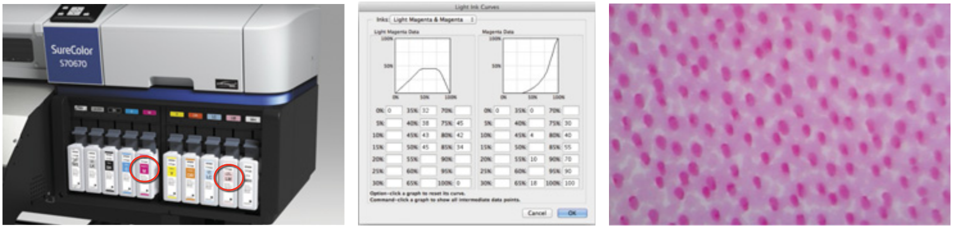
RIPs and profiling software offer tools for ink limiting that address the issue of ink hooking, prior to printing the characterization chart.

8.3.3 Ink Splitting

Most inkjet devices use two inks for each channel, for example, a light magenta (LM) and a normal magenta (M) ink, Figure 8.4a. The splitting of ink between the light magenta and normal magenta can be controlled via a dialog in the RIP, Figure 8.4b. In this figure we see that the light ink increases up until around the mid-tones, levels off, then eventually tapers off. From the mid-tones (around 50%), the normal magenta ink cuts in, ramps up, and is used more and more in the darker tones of the image. Typically light inks may be used in the highlights and then merged with normal inks at the mid-tones to shadows. Figure 8.4c shows a printed area that contains light magenta ink (background) and normal magenta ink (foreground).

Where and how ink splitting occurs needs to be determined during the calibration stage of inkjet profiling. This control should not be altered after a profile has been made.

When considering the color capability of inkjet printers with many inks, there is a tendency to conclude that "more ink cartridges = more gamut." It is important to note that, contrary to popular myths, light inks do not contribute to an increase in gamut extent. If a printer has orange, green or violet inks, these are expected to increase



Inks: Light Magenta & Magenta

Light Magenta Data: 0%: 0; 35%: 32; 40%: 38; 45%: 43; 50%: 45; 75%: 45; 80%: 42; 85%: 34; 100%: 0

Magenta Data: 0%: 0; 35%: 0; 45%: 4; 55%: 10; 65%: 18; 75%: 30; 80%: 40; 85%: 55; 90%: 70; 95%: 90; 100%: 100

Option-click a graph to reset its curve.
Command-click a graph to show all intermediate data points.

(a) (b) (c)

Figure 8.4 (a) Inkjet printers use two inks for some colors, such as magenta and light magenta. (b) RIP software, such as ColorBurst, directs ink splitting into two separate cartridges. (c) A magnified inkjet print sample shows drops of magenta ink over a background of light magenta ink. Image (a) *Source:* Epson. Reproduced with permission of Epson.

the printer gamut, however light inks are used in the lighter areas of an image to improve tonality in these areas and does not contribute to creating a larger gamut volume.

In order to evaluate the color created by light inks, consider a three-dimensional L*a*b* analysis of the light inks and normal inks for an inkjet printer, Figure 8.3. In the L*a*b* diagram, the light cyan, light magenta, and light black inks all have a smaller chroma compared to normal inks. From this figure we can clearly see that the light inks do not push or extend the color gamut and therefore do not increase the gamut extent of the system. (Note that inkjet printers never have light yellow, as yellow is already a light color.)

It is interesting to note from Figure 8.3 that the diluted light inks are at a slightly different hue compared to the normal inks; the hue difference is relevant but nothing to worry about as it would be accounted for by the action of an ICC profile.

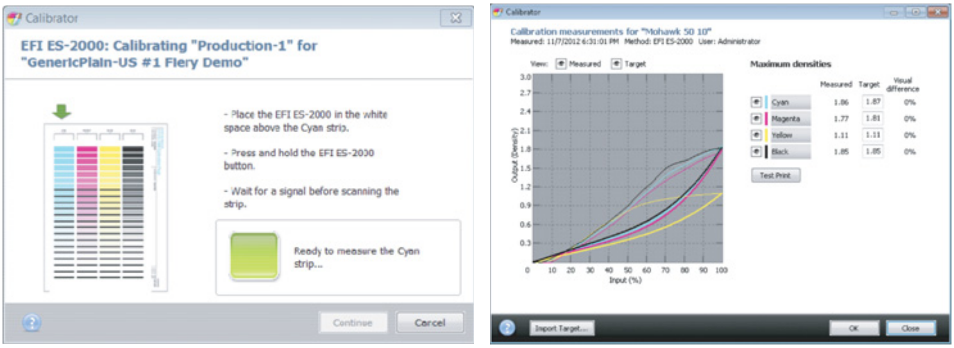
8.4 Calibration in Digital Presses

Digital presses are categorized by their xerographic printing process that uses toner particles, a photo-conductive drum, a corona charging wire, a transfer belt and a high-temperature fusing process. The print speed of a digital press is typically 70–100 letter pages per minute (ppm), and a press is controlled by a digital front end (DFE), also called a controller. All color devices in the digital press category with a DFE/controller, are able to fully support ICC color management.

The main calibration process for a digital press is called *paper calibration*, Figure 8.5. Paper calibration will usually involve printing and measuring CMYK ramps.

Calibration for a digital press may be used after an environment change, a mechanical change such as a parts replacement, or most commonly for the effect of a different paper type. In digital presses, calibration is also used as process control, to adjust the press response and return to a known state.

Digital press calibration is typically directed by DFE software, Figure 8.5b. A press operator will typically print and measure CMYK ramps. Depending on the digital press



EFI ES-2000: Calibrating "Production-1" for "GenericPlain-US #1 Fiery Demo"

- Place the EFI ES-2000 in the white space above the Cyan strip.
- Press and hold the EFI ES-2000 button.
- Wait for a signal before scanning the strip.

Ready to measure the Cyan strip...

Calibration measurements for "Mohawk 50 10"
Measured: 11/7/2012 6:31:01 PM Method: EFI ES-2000 User: Administrator

Maximum densities

	Measured	Target	Visual difference
Cyan	1.86	1.87	0%
Magenta	1.77	1.81	0%
Yellow	1.11	1.11	0%
Black	1.85	1.85	0%

(a) (b)

Figure 8.5 (a) The EFI Fiery Command WorkStation conducts a digital press calibration from measurements of CMYK ramps. (b) During calibration, software computes adjustments to ensure optimum press performance.

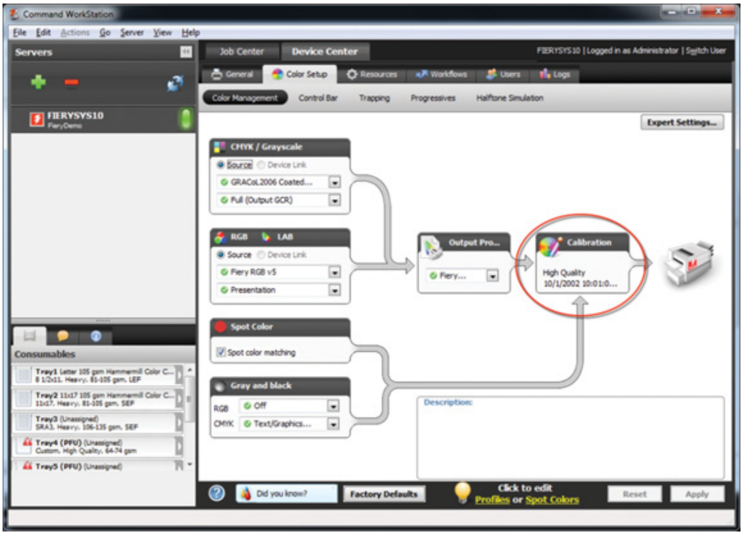

Command WorkStation
File Edit Actions Go Server View Help
Servers
FIERYSYS10
FieryDemo
Job Center
Device Center
FIERYSYS10 | Logged in as Administrator | Switch User
General
Color Setup
Resources
Workflows
Users
Logs
Color Management
Control Bar
Trapping
Progressives
Halftone Simulation
Expert Settings...
CMYK / Grayscale
Source
Device Link
GRACoL2006 Coated...
Full (Output GCR)
RGB
LAB
Source
Device Link
Fiery RGB v5
Presentation
Spot Color
Spot color matching
Gray and black
RGB
Off
CMYK
Text/Graphics...
Output Pro...
Fiery...
Calibration
High Quality
10/1/2002 10:01:0...
Description:
Consumables
Tray1 Letter 105 gsm Hammermill Color C...
8 1/2x11. Heavy. 81-105 gsm. LEF
Tray2 11x17 105 gsm Hammermill Color C...
11x17. Heavy. 81-105 gsm. SEF
Tray3 (Unassigned)
SRA3. Heavy. 106-135 gsm. SEF
Tray4 (PFU) (Unassigned)
Custom. High Quality. 64-74 gsm
Tray5 (PFU) (Unassigned)
Did you know?
Factory Defaults
Click to edit
Profiles or Spot Colors
Reset
Apply

Figure 8.6 EFI Fiery Command WorkStation is a popular DFE for a digital press. A number of workflow paths are shown by arrows – paths for every type of image end up using the paper calibration.

model and configuration, the calibration target can be measured using a spectrophotometer. In digital presses with a scanner the target can be "measured" by the scanner. A common supported instrument for digital press calibration is the X-Rite i1Pro2 spectrophotometer, or OEM versions, called for example, EFI ES-2000, as shown in an earlier chapter, Figure 4.12i.

During calibration, software computes and applies corrections to bring the print process back to a previously determined condition. If the machine has drifted then doing a calibration gets us back to where we were. Calibration should be done if the output has a lower density than expected, a print shows color casts, or any other unwanted color or imaging artifacts, such as blocked highlights or shadows, or unevenness. In addition, digital presses use information about the paper to adjust internal operating parameters such as fuser temperature.

The calibration file provides a foundation for the selected output profile. In fact it is not possible to print without reference to the calibration file, as shown in the EFI Command WorkStation DFE, Figure 8.6. Note that every image path, passes through the calibration stage on the way to the press.

8.5 Calibration in Offset Printing

In offset lithography, there are a number of aspects of the printing process that must be known and controlled during the calibration process. Offset printing is a complicated analog printing process, and there are many factors that can impact printed color such as the printing inks, the paper, press materials (such as fountain solution, blankets, rollers), the printing plate, settings for the computer-to-plate unit, settings for the target density and ink keys on the press, ink sequence, ink trapping, etc.

What is required in a press calibration system is the ability to establish a baseline setting, a quick and easy way to monitor and determine if we have deviated from that baseline calibration, and a way to easily return the press to its calibrated state.

There are many calibration methods available, each with different philosophies and ways of working, but something they all have in common is that they all create better consistency when printing and proofing and provide a good starting point for subsequent ICC color management.

The ProcessStandard Offset (PSO) procedure is developed by Fogra in co-operation with the German Printing and Media Industries Federation (BVDM). It is a description of an industry-oriented and standardized procedure for the creation of printed products. The Idealliance G7 process is another calibration method, and there are other calibration methods including Gray Balance Optimization from Heidelberg and System Brunner used widely in European offset printing.

We now consider the G7 process as an example of a calibration process for offset printing.

8.5.1 G7 Calibration

The G7 calibration process can be applied to offset printing, and other CMYK printing processes. G7 is based on gray balance. We are very susceptible to a color cast in neutral colors, so by removing any color cast in the neutral or gray colors, we can create a "gray-balanced" image. An old saying from the days of darkroom photography is "get it right in black and white," in other words remove any color cast from the image.

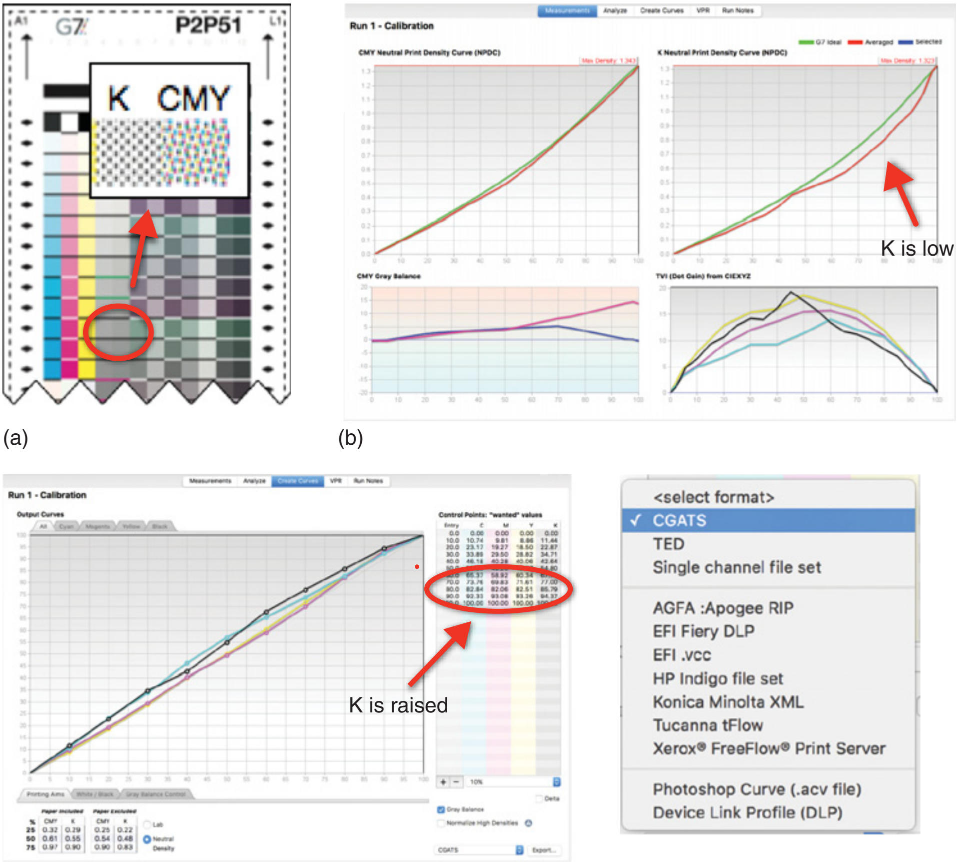
It has long been known that to create a neutral color with offset inks, we require unequal CMY amounts. There is a general rule of "50, 40, 40" for a CMY mix that will create a neutral mid-tone gray. In general every printing ink set will require a different ratio of cyan:magenta:yellow, to create neutral gray. The determination of these relative amounts for your printing system, is the underlying principle of G7.

G7 is based on creating a relationship between the CMY-black and K-only black, and is based on the paper used, and the highest densities the printing process can achieve. Consider Figure 8.7 that shows the steps of the G7 calibration process.

(a) To begin, a target called the P2P is printed on the device. P2P stands for "press-to-proof." The P2P target consists of two ramps of gray, one containing cyan, magenta and yellow ink, and the other consisting of black ink only. The P2P target has different version numbers and formats and vendors may incorporate the P2P patches into their own proprietary target, or create their own version of the target.

(b) The P2P target is printed and measured and then dedicated software is used for analysis, one example of which is Chromix Curve4. Curve4 analyzes the CMY and K response. The ideal G7 calibration curve is shown in green and the device's current response is in red. To achieve G7 calibration, the CMY and K curves should approximate the G7 tone curve shape. In the example the CMY curve is OK, but the K channel requires corrective action.

(c) We see that in this example, the black channel in the printer is too low and does not create an accurate G7 tonal response. The Curve4 program calculates a correction so that the CMY values are left largely unchanged, but the black channel is increased.


G7
P2P51
K CMY
Run 1 - Calibration
CMY Neutral Print Density Curve (NPDC)
K Neutral Print Density Curve (NPDC)
G7 Ideal
Averaged
Selected
K is low
CMY Gray Balance
TVI (Dot Gain) from CIEXYZ
Output Curves
Control Points: "wanted" values
K is raised
<select format>
✓ CGATS
TED
Single channel file set
AGFA :Apogee RIP
EFI Fiery DLP
EFI .vcc
HP Indigo file set
Konica Minolta XML
Tucanna tFlow
Xerox® FreeFlow® Print Server
Photoshop Curve (.acv file)
Device Link Profile (DLP)

(a) (b)

(c) (d)

Figure 8.7 The G7 process in Chromix Curve4. (a) A P2P target contains ramps of single-black, and 3-color black. (b) Curve4 software compares the P2P measurements to an ideal G7 curve for CMY and K. (c) A correction is calculated that brings the device into G7 alignment. (d) The correction values can be exported in different file formats.

Where K originally had 70% the correction lookup table now suggests 77%, and 80% becomes 85%, etc.

(d) This correction lookup table seeks to adjust the printed ramps, to better approximate the G7 curve, in order that the printing system be "G7 calibrated." The correction lookup table can be exported and applied via a RIP, platesetter, Photoshop, or other workflow system, perhaps as a CGATS text file.

In the final part of the process the correction can be applied to the printing system, and the P2P target can be re-printed and re-measured to verify the new result. To confirm if you meet G7 calibration conditions you can ask Curve4 software to "Verify," or a skilled user can do the math themselves using published G7 pass/fail criterion. In official certification processes the re-printed P2P target may be sent to a designated laboratory for independent measurement and verification.

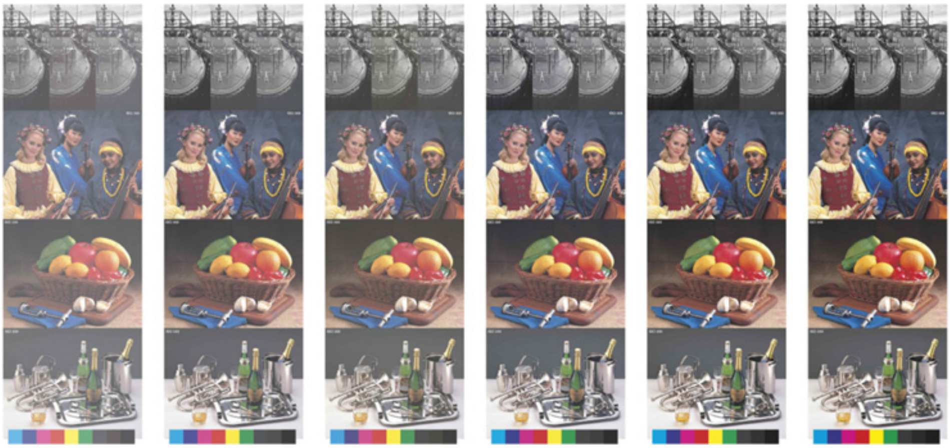


Figure 8.8 G7 calibration creates a similar neutral appearance across different types of printing processes from newsprint to premium coated stock. Courtesy of Don Hutcheson, SCID images ©ISO 12640.

8.5.2 Shared Neutral Appearance vs. Full Color Match

The G7 curve is a particular chosen tone curve shape which is described in a public-domain, free technical report called TR 015.[1] The document allows manufacturers to implement and generate the G7 response within their applications and systems.

It is useful to note that G7 curves are created dynamically for each specific print process from the supplied measurement data. While the curve shape is defined in TR 015, the top and bottom of the curves “float” and start at the white point of the printed sample and end at the darkest, solid ink patches. Because of this, the G7 process, at the low end, works as a relative function of the brightness and color of the supplied paper type, and at the top end does not reduce the density of the print process.

As the G7 calibration process is based on a visual attribute of gray balance, we see that it is possible to describe a *shared neutral appearance* where the same image on different printing processes retains the same look and feel. In the situation where the G7 process is applied to similar printing systems, e.g. offset lithography, where two offset presses are using the same paper, inks, and operating to the same press conditions, then application of the G7 calibration process can create a similar appearance. In the case of a shared neutral appearance the images may not be an exact color match, but nevertheless create the same impression in highlights, mid-tones and shadows, Figure 8.8. We may say that G7 calibration can create a similar neutral appearance on different printing processes, relative to the substrate and available solid ink density of each process.

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[1] CGATS/IDEAlliance TR 015-2015 *Graphic Technology – Methodology for Establishing Printing Aims Based on a Shared Near-neutral Gray-scale.*

Most of the time, when using different print processes, in order to obtain a complete match in all aspects of color beyond simply tonality, we must consider ICC-profile based color management. G7 is a calibration procedure, and in common with other calibration procedures, it would normally be followed by application of ICC profiles, according to the three Cs of color management – calibration, characterization and conversion.

8.6 Printer Test Charts

We have described color management as consisting of the three Cs – calibration, characterization, and conversion. We have just considered aspects of calibration for different printing processes, after calibration, the next C is *characterization*, also commonly referred to as "profiling."

In characterization, we study the print process by printing and measuring a test chart. A printer test chart is a digital file, usually a TIFF file, containing patches of known value. The chart is usually CMYK, but can also be RGB or a multi-color chart, for example CMYK + orange + green.

The most accurate way of studying the printer response would be to print and measure every CMYK combination. However this would run into millions of colors and would take a week to measure! Therefore, profiling vendors require us to print and measure a target that contains a subset of CMYK combinations. From this data, vendors create a model of the device behavior. The model is then used to calculate data for the printer profile color lookup tables. The quality of the printer profile will depend on how well the vendor is able to model the mixing of the printing inks, and the accuracy with which the vendor populates the color lookup tables.

There are a range of chart types to choose from. Let's look at some of the issues involved in selecting, printing, and measuring a printer test chart.

8.6.1 Commonly Used Printer Test Charts

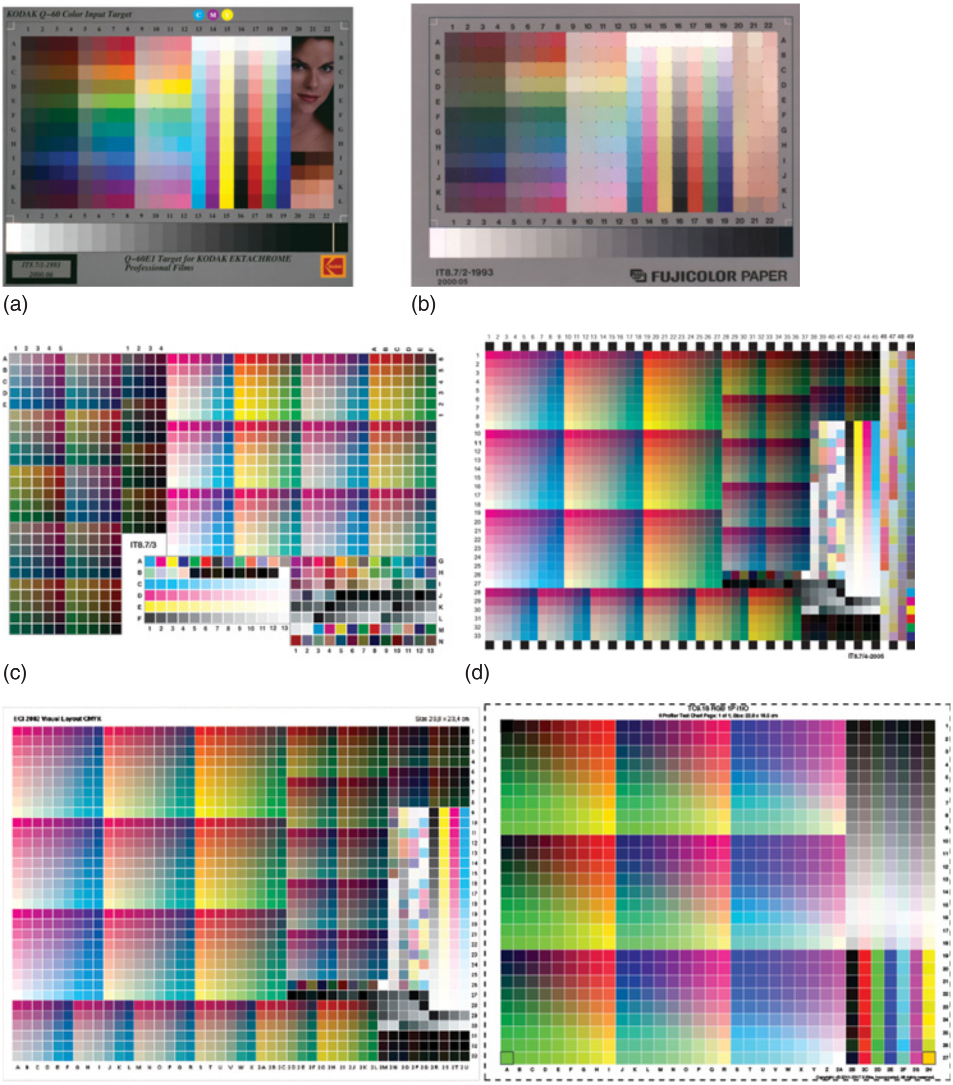
Figure 8.9 shows the currently available charts for different types of profiling.

(a) **IT8.7/1** is a scanner target – it is not for printers, but the numbering system for the IT8 series of charts started with scanners. The IT8.7/1 target is used to calibrate a scanner when scanning photographic transparency material.

(b) **IT8.7/2** is a scanner target produced on photographic paper, and is used for profiling a scanner for photographic prints, its layout is similar to the IT8.7/1 target.

(c) **IT8.7/3** is an obsolete chart for CMYK printer characterization. A lower section of the chart can be used on its own and is called the basic set (182 patches), while the whole chart is called the extended set containing 928 patches. The chart has areas dedicated to measuring solid CMYK values, overprints, and saturated colors. The IT8.7/3 chart has been superseded by the IT8.7/4 chart.

(d) **IT8.7/4** is the current industry standard printer chart, it contains 1617 patches described by their CMYK values. The IT8.7/4 chart is an updated version of the IT8.7/3 chart, with some added patch values. In developing the IT8.7/4, many in the color management community felt that additional data points were needed to provide a better sampling of the printer color space. There was also a request from the packaging industry which wanted to see more data points at the highlight end of the scale. The IT8.7/4 provides a better sampling of the color space by increasing the number of sample points


KODAK Q-60 Color Input Target
Q-60E1 Target for KODAK EKTACHROME Professional Films
IT8.7/1-1993
IT8.7/2-1993
FUJICOLOR PAPER
IT8.7/3
ECI 2002 Visual Layout CMYK

(a) (b) (c) (d) (e) (f)

Figure 8.9 Scanner and printer test charts (a) IT8.7/1 is a scanner transparency chart. (b) IT8.7/2 is a scanner reflection chart. (c) IT8.7/3 is an obsolete printer test chart. (d) IT8.7/4 has 1617 patches and is the recommended test chart for printer profiling. (e) ECI 2002 from the European Colour Initiative is supported by most profiling software. (f) Proprietary RGB chart from X-Rite i1Profiler.

and there are new patches that are especially appropriate for the packaging industry. The changes involve more samples at the low and high end of the single-color scales. For example, the color scales in the IT8.7/3 had dot percentages of 100, 90, 80, 70, 60, and so on, while in the IT8.7/4 chart the values in the shadow region are 100, 98, 95, 90, 85, 80, 75, 70, 60, etc. The IT8.7/4 contains all of the patches that are found in the IT8.7/3 chart and many programs are able to extract the IT8.7/3 data from IT8.7/4 measurement data. The IT8.7/4 is described by an international standard – ISO 12642. ISO standards are reviewed every five years, and ISO 12642 describing the IT8.7/4 chart, was last reviewed in 2015. *The IT8.7/4 1617 patch CMYK chart is highly recommended for all printing processes including publication and commercial offset printing and package printing with offset, gravure, and flexography. The chart is used widely for xerographic processes, large format inkjet, and inkjet printers and proofers.*

(e) **ECI 2002** is another replacement consideration for the IT8.7/3 chart. The European Color Initiative (ECI) test chart comprises 1485 patches and has aspects that are similar to both the IT8.7/3 and IT8.7/4. Many profiling vendors use (and sometimes recommend) the ECI 2002 target for printer profiling. The chart can be used for profiling every kind of conventional and digital CMYK printing process. The ECI 2002 patches are totally contained and are easily extracted from the IT8.7/4 chart.

(f) **Proprietary RGB charts**. Occasionally printing systems may be treated as RGB devices, such as when profiling an inkjet printer via a printer driver for photographic use. There are no standard RGB test charts, so most RGB charts tend to be proprietary, where the user describes the number of patches and the required dimensions, and the profiling software creates a test chart and corresponding reference file.

In the early days of color management, some vendors preferred to use a proprietary chart created within their own software, because their charts were specially designed to support their internal profiling algorithms. While a proprietary CMYK chart is still a viable option, there is no longer a pressing need, given the increased number of patches now readily available in the IT8.7/4 chart. Further, using a proprietary chart limits interoperability relating to control strips, reporting ΔE, etc. Today a proprietary CMYK test chart would only be used in special instances, for example, if there is a particular color of interest and we wish to introduce patches of that color into the test chart, or there is not enough real estate on the press sheet and a smaller test chart is required.

In areas of printing involving extra colorants such as orange, green and violet, there are no standardized CMYK+OGV charts, so all CMYK+ targets will in general, be proprietary. We see that if there are more than four channels, and it is necessary to specify the colorants of the extra channels.

In the case of the scanner test charts (IT8.7/1 and IT8.7/2), the material type is known, and the chart is carefully created in such a way that the patch values are well distributed in terms of L*a*b*. For the printer targets (IT8.7/3 and IT8.7/4), the patch values are equally spaced, we may say that the chart is designed in equal CMYK increments, but the measurement data (in L*a*b*) may not be uniformly distributed, creating sparse sample points in some areas of the color space.

Due to the complex way that the national bodies and international standards organizations function, the printer charts continue to evolve, and there are always interesting discussions as new applications arise that necessitate some new patch values or layout considerations. Nevertheless the IT8.7/4 chart is supported by every system today and will be the main choice of color management for the foreseeable future.

8.6.2 Visual vs. Random Layout

Printer charts are often available in "visual" and "random" versions, Figure 8.10. Inkjet printers are designed to print continuously changing pixel values and when asked to deposit relatively large areas of a fixed ink combination, can suffer "ink starvation" issues.

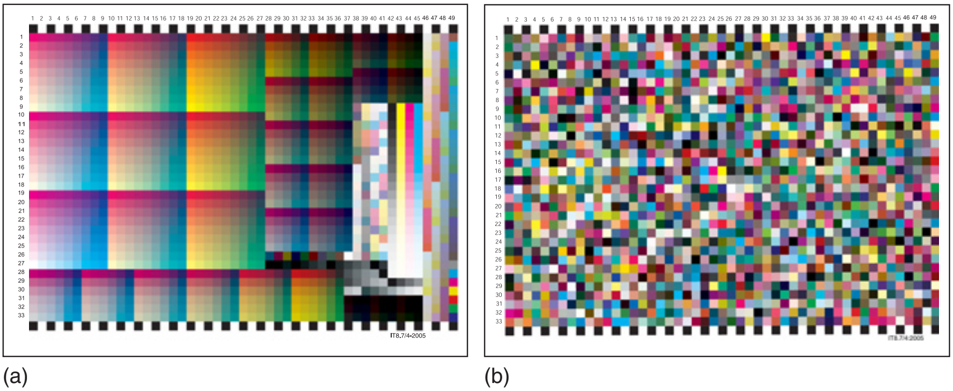

(a) (b)

Figure 8.10 The IT8.7/4 is available in equivalent (a) visual, or (b) random formats. The random layout prevents ink starvation in inkjet printing systems.

To avoid ink starvation (or over-inking), uniform ink loading in each color across the target area is achieved using a random version of the printer chart.

The patch values between the visual and random version of a chart are the same, only the layout changes. Note that a "random" layout really means "scrambled," as the layout is not random at all – the value and location of each patch is carefully considered.

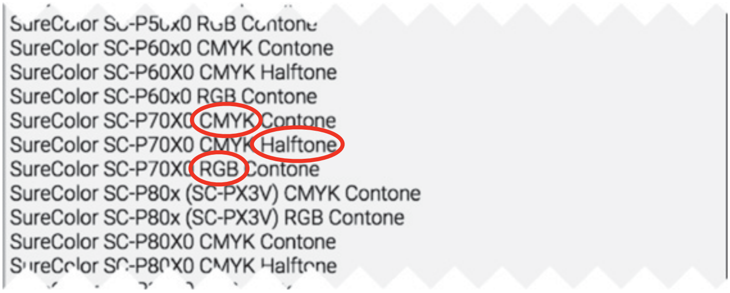
One issue when using the random version of a chart is that it is difficult to find specific patches for analysis – it is not easy to evaluate the neutral ramp or identify the solid inks or the paper white point. This is generally not a problem, as all software solutions can rearrange the patches and display measurement data in easy to understand visual format, irrespective of the test chart used.

8.7 Printing and Measuring the Test Chart

Once a test chart has been selected, the next step is to print and measure it. The test chart must be printed at an appropriate size so that the patches can be read by your chosen measuring instrument. During printing of the chart it is necessary to ensure that "no color management" is used. Let us look at these steps, which will lead us soon, to the final stage of making a printer profile.

8.7.1 RGB or CMYK or Halftone Printer?

Devices such as inkjet printers and proofers can be classified as either RGB or CMYK or Halftone printers, Figure 8.11. In RGB and CMYK modes, image data is handed to the printer driver and printer libraries to complete the printing process, while in the Halftone mode RIP software fully controls the printing process, right up to and including driving the print heads. All three modes are usually available for each printer type, irrespective of the actual number of inks in the system. Each mode has advantages and disadvantages, as described below. It is important that the mode used is the same between profiling and printing, in other words the same mode should be used to print the test chart and the subsequent print job.



SureColor SC-P50x0 RGB Contone
SureColor SC-P60x0 CMYK Contone
SureColor SC-P60X0 CMYK Halftone
SureColor SC-P60x0 RGB Contone
SureColor SC-P70X0 CMYK Contone
SureColor SC-P70X0 CMYK Halftone
SureColor SC-P70X0 RGB Contone
SureColor SC-P80x (SC-PX3V) CMYK Contone
SureColor SC-P80x (SC-PX3V) RGB Contone
SureColor SC-P80X0 CMYK Contone
SureColor SC-P80X0 CMYK Halftone

Figure 8.11 This dialog from EFI Fiery XF shows that the same Epson SureColor P7000 inkjet printer can be addressed in RGB, CMYK or Halftone modes.

RGB Printers

Today, many inkjet printers are treated as if they are *RGB printers*, making them an obvious choice for the photography market. For many printers, such as Epson and Canon inkjet printers, it is possible to print using a printer driver using RGB data. No special software is needed as printer drivers are often pre-installed with Windows and macOS, or are available from the printer manufacturer's web site. The user prints directly from any supported application, such as Adobe Photoshop or Adobe Lightroom or Apple Photos, and the printer driver performs a conversion from RGB to the available inks, and then prints the image using the printer's ink set. In the RGB print mode, the configuration of the printer is done via printer driver dialogs, and the manufacturer's print engine "manages" the printing process.

There is a variation of the RGB mode, where commercial solutions don't use the printer driver itself, instead call upon the libraries of the RGB printer driver. These systems offer an improved interface and productivity options. Products that use the RGB printer libraries include ColorBurst Overdrive, ColorByte ImagePrint, and EFI Fiery XF in "RGB Contone" mode, Figure 8.11.

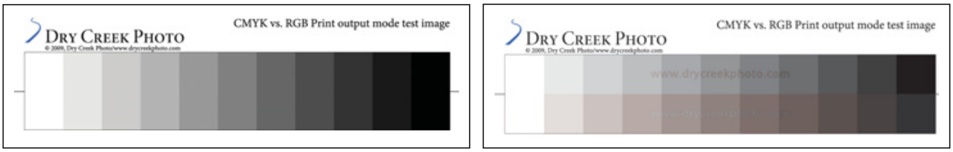
To profile a printer in RGB mode, we would use an RGB chart and assume that the color processes performed by the printer driver or printer libraries represent a "static, black box."

CMYK Printers

Another common approach is to print to an inkjet device treating it as a *CMYK printer*. The prepress and proofing market uses third-party RIP software to send CMYK instructions to a printer. In CMYK printing some linearization and calibration processes are conducted, and applied by the user via a RIP, before handing the CMYK data to the printer libraries to complete the printing process. The printer libraries manage the remainder of the process, including splitting the inks into light channels and using the extra inks as available (e.g. orange, green, violet).

Most proofing RIP software, such as EFI Fiery XF or ONYX or workflow software such as Kodak Prinergy or Esko Automation Engine address a printer in CMYK mode.

To profile a printer in CMYK mode, we would use a CMYK chart and assume that the color processes performed by the printer libraries represent, a "static, black box."


DRY CREEK PHOTO
CMYK vs. RGB Print output mode test image
DRY CREEK PHOTO
CMYK vs. RGB Print output mode test image
www.drycreekphoto.com

(a)

(b)

Figure 8.12 This test image is used to determine if you have an RGB or CMYK printer. If your printed image looks like (a), this indicates a printer operating in RGB mode. (b) is the response of an inkjet printer in CMYK mode. *Source:* Dry Creek Photo. Reproduced with permission of Dry Creek Photo.

Halftone Mode

The Halftone mode, where offered, is a "true" print mode. In this mode the RIP software screens the image into halftone dots, splits the inks between light cyan/cyan, maps the colors to an extra inks such as CMYKOG, CMYKRGB, sets the print resolution and instructs the inkjet heads to deposit various amounts of ink on the paper. The print heads are directly controlled and all aspects of the printer are controlled by the RIP software. This is an advanced printing mode that can be used in applications that seek to, for example, create a dot proof or modify print engine settings that are not allowed in the other print modes.

There needs to be a market demand before third-party RIP software (EFI Fiery XF, CGS ORIS, GMG ColorDrive, ONYX Thrive) develop a Halftone driver, and all the mentioned products have a web site with long searchable lists of which printer models are supported in which mode. In most cases the Halftone mode is the last option that developers add to the list and then only in response to customer demand. Despite being at the end of the "wish list," the halftone print mode is the only way to correctly profile a printer with an extended ink set. For complete control of the printer engine, the Halftone route is preferred, when available.

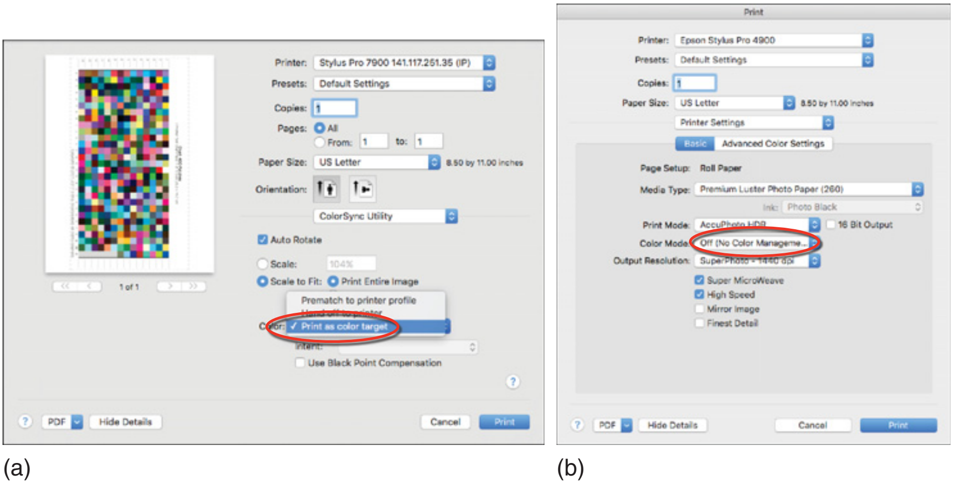
There are many test images that can be used to determine whether you are using an RGB or CMYK workflow, Figure 8.12. This simple pattern contains a K only (top row) and CMY mix (lower row). Print the image to the desired printer. If both top and bottom gradients appear similar, you have an RGB printer, if the bottom gradient is a muddy color, as shown here, you have a printing pipeline that assumes CMYK data.

So we see that it is often possible to profile the same device as an RGB or CMYK or Halftone device. Your approach will depend on your workflow, the hardware/software you have, and the results you are getting in each mode.

8.7.2 Printing with "No Color Management"

Most profiling software will offer you the choice of printing a test chart directly from within the profiling application or saving the chart as a TIFF file to the desktop and then printing it. What is important, but not always easy to do, is to print the chart with "no color management."

During printing of the test chart, we are trying to record the default color behavior of the device, so it is important that the test chart is printed with no color corrections or application of ICC profiles. It is necessary to enable any calibration or other baseline settings, but there should be "no color management" applied.



(a)

Printer: Stylus Pro 7900 141.117.251.35 (IP)
Presets: Default Settings
Copies: 1
Pages: ● All
○ From: 1 to: 1
Paper Size: US Letter 8.50 by 11.00 inches
ColorSync Utility
☑ Auto Rotate
○ Scale: 104%
● Scale to Fit: ● Print Entire Image
Prematch to printer profile
Color: ✓ Print as color target
Intent:
☐ Use Black Point Compensation

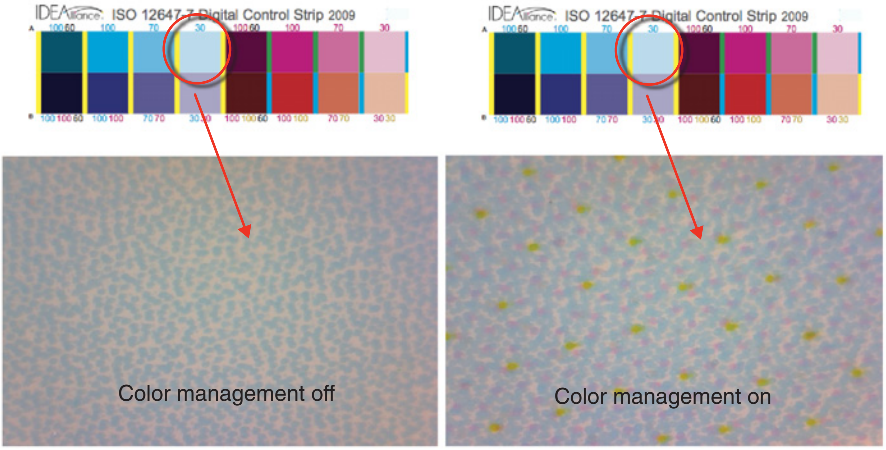
(b)

Print
Printer: Epson Stylus Pro 4900
Presets: Default Settings
Copies: 1
Paper Size: US Letter 8.50 by 11.00 inches
Printer Settings
Basic | Advanced Color Settings
Page Setup: Roll Paper
Media Type: Premium Luster Photo Paper (260)
Ink: Photo Black
Print Mode: AccuPhoto HDR ☐ 16 Bit Output
Color Mode: Off (No Color Manageme...
Output Resolution: SuperPhoto - 1440 dpi
☑ Super MicroWeave
☑ High Speed
☐ Mirror Image
☐ Finest Detail

Figure 8.13 Printing the test chart with no color management can be done using (a) ColorSync Utility with "Print as color target" or (b) via a printer driver with Color Mode "Off (No Color Management)."

ColorSync Utility, available as part of macOS, allows printing of a test chart without color management – "Print as color target," Figure 8.13a. And, if printing an RGB chart via an RGB printer driver, turn off color management in the appropriate dialog, Figure 8.13b. The Adobe Color Printer Utility also allows printing of a test target with no color management on Windows or macOS.

One easy way to determine if color management has been used or not, is to examine any single color patch and make sure that it is "clean," i.e. the printed patch when viewed under a loupe should only contain the colorants specified in the digital file and not other colored inks, Figure 8.14a. If we see small amounts of other color inks added during printing, this suggests that color management was used during printing, Figure 8.14b.



IDEAlliance ISO 12647-7 Digital Control Strip 2009
Color management off
IDEAlliance ISO 12647-7 Digital Control Strip 2009
Color management on

Figure 8.14 There is a simple test to confirm if color management is off during printing. (a) If color management is off, a pure color is printed with a single ink. (b) With color management on, we may see many colored inks.

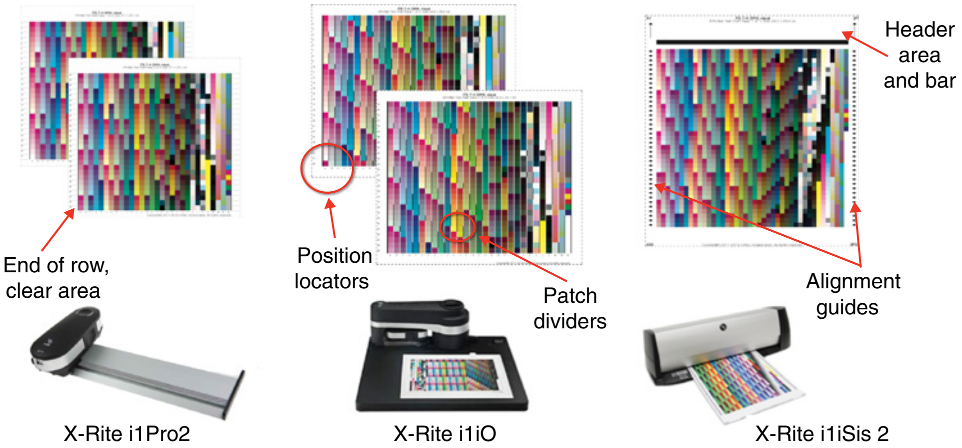


Figure 8.15 The IT8.7/4 chart can be configured for (a) the X-Rite i1Pro2 (b) the X-Rite i1iO or (c) the X-Rite iSis2 XL. Each measuring instrument requires different markers, guides and patch dividers. X-Rite i1Pro2 image *Source:* Courtesy of Keith Cooper. Other images *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

8.7.3 Layout for Different Measuring Instruments

To obtain a good profile it is necessary to take care in the measuring process. There are a number of practical issues to consider.

All charts described so far (ECI 2002, IT8.7/4, etc.) may be formatted in different shapes and sizes to suit different measuring instruments. The chart content is normally unchanged, but the layout may be altered to match the chosen measurement device. Each measuring instrument requires different markers, guides and patch dividers. Often devices need fiducial markers to identify the chart orientation and to identify the header in an automated reader, for machine and pattern recognition.

Figure 8.15 shows the same IT8.7/4 chart formatted for the X-Rite i1Pro2 strip reader, the X-Rite i1iO table, and the X-Rite i1iSis2 auto-scanning instrument. The X-Rite i1Pro2 needs a clear area at the start and end of each row. The X-Rite i1i0 has position locators at the corner of each page, and the chart has dividing bars between each patch with enough contrast for the instrument to determine the end of a patch and the start of the next patch. The X-Rite iSis 2 XL has diamond shaped alignment guides and a 1.5” header.

When a chart has been printed there are a few things to check. Most charts will have crop marks or registration marks for the hardware to locate and recognize the chart border. It is necessary to confirm that the printer has not clipped these marks, and you should not trim them from the print border. (Experienced users will have at some time used a Sharpie to add lines to a chart or have used sellotape to repair the header of a target that was unintentionally trimmed.)

It is important to consider the physical size of the printed chart. The size of the chart should not be inadvertently altered during the printing process to fit on a page or to fit with other images on a sheet. Each instrument has a minimum patch size. If imaged at a smaller size, this could cause problems in reading the chart.

8.7.4 White Backing

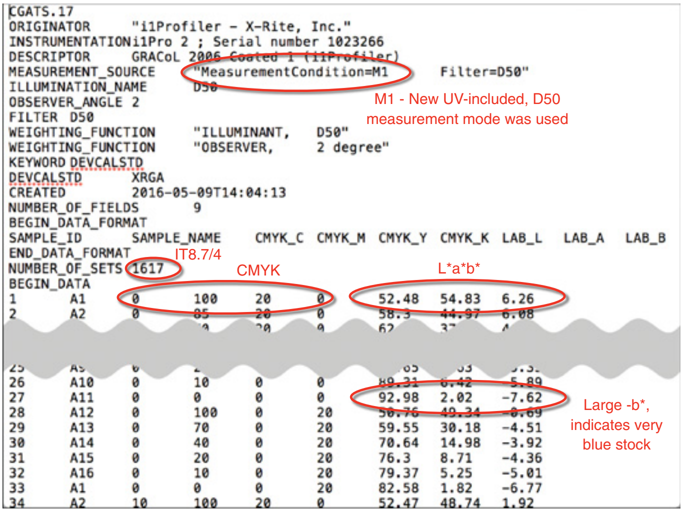
There are many things that can affect an accurate reading of the chart. The necessary precautions will vary, depending on your situation. For example, charts from inkjet printers should be allowed to dry before measuring. Other measurement problems can result from such things as a chart that is not flat, a speck of dust on a patch, smeared patches, incorrect alignment of a chart, and incorrect printing of a chart.

Sometimes the chart may be printed on paper that is not opaque enough, so the color of the backing or an image printed on the reverse shows through. It is a good idea to print the chart on one side only, even if the real job will be printed on both sides of the sheet. In many situations, it is helpful to place one or more unprinted sheets under the sample during measurement. For some instruments, you can select a white or black backing option. Today white backing, or same sheet backing, is the norm.

When reading the chart most software will show you on the screen an image of the chart with an indication of the patch it is expecting you to measure. Some vendors will perform automatic checks on the measurement data, for example, whether the data is non-monotonic, or if the white patch is dirty.

8.7.5 Examining the Measurement File

After a test chart is printed and measured, it is possible to save the measurement data as a text file, Figure 8.16. The measurement file is an ASCII file that can be opened in any text editor. We see that the header should indicate the measurement condition, and today the recommended measurement mode is M1, which represents a UV-included, D50 measurement condition. The header shows that 1617 patches were measured, an indication that the data comes from an IT8.7/4 chart.



```
CGATS.17
ORIGINATOR      "i1Profiler - X-Rite, Inc."
INSTRUMENTATIONi1Pro 2 ; Serial number 1023266
DESCRIPTOR      GRACoL 2006 Coated 1 (i1Profiler)
MEASUREMENT_SOURCE     "MeasurementCondition=M1      Filter=D50"
ILLUMINATION_NAME      D50
OBSERVER_ANGLE 2
FILTER  D50
WEIGHTING_FUNCTION     "ILLUMINANT,    D50"
WEIGHTING_FUNCTION     "OBSERVER,      2 degree"
KEYWORD DEVCALSTD
DEVCALSTD       XRGA
CREATED         2016-05-09T14:04:13
NUMBER_OF_FIELDS       9
BEGIN_DATA_FORMAT
SAMPLE_ID       SAMPLE_NAME    CMYK_C  CMYK_M  CMYK_Y  CMYK_K  LAB_L   LAB_A   LAB_B
END_DATA_FORMAT
NUMBER_OF_SETS 1617
BEGIN_DATA
1       A1      0       100     20      0       52.48   54.83   6.26
2       A2      0       85      20      0       58.3    44.97   6.08
26      A10     0       10      0       0       89.31   6.42    -5.89
27      A11     0       0       0       0       92.98   2.02    -7.62
28      A12     0       100     0       20      50.76   49.34   -0.69
29      A13     0       70      0       20      59.55   30.18   -4.51
30      A14     0       40      0       20      70.64   14.98   -3.92
31      A15     0       20      0       20      76.3    8.71    -4.36
32      A16     0       10      0       20      79.37   5.25    -5.01
33      A1      0       0       0       20      82.58   1.82    -6.77
34      A2      10      100     20      0       52.47   48.74   1.92
```

M1 - New UV-included, D50 measurement mode was used
IT8.7/4
CMYK
L*a*b*
Large -b*, indicates very blue stock

Figure 8.16 The test chart measurement file is a text file that shows the M1 measurement mode, 1617 patches of the IT8.7/4 test chart and a list of CMYK – L*a*b* measurements. Row 27 shows measurement of very blue paper stock.

Looking at the measurement file confirms our understanding of color management and printer profiling in particular. The first part of the measurement file contains a list of CMYK values, which are the patch values in the test chart that was sent to the printer. Paired with each CMYK value is a measurement of that printed color in units of L*a*b*. A measurement file could also contain XYZ or spectral data for each patch.

A profiling application will take the CMYK–L*a*b* pairs, build a mathematical model, populate the lookup tables, and finally create an ICC profile file in which to store the lookup tables for ICC-aware applications to use.

In the measurement file, it is useful to find the solid ink densities, e.g. CMYK of 100, 0, 0, 0 represents 100% cyan. It is also possible to find the white patch with no inking, CMYK of 0, 0, 0, 0, which represents a measurement of the substrate, often called the "paper white" value. In this example the white point has a large $-b^*$ value which indicates a paper that probably contains optical brightening agents.

It is normally possible to save the measurement data and then continue to profile generation. If the measurement data is saved it can be used at a later date. One reason to keep the measurement data is if you want to remake the profile to change the black generation settings. If the measurement file was created in a standard format it can often be used in another program to see how different vendors compare, or it can be used to analyze the gamut of the device by using a utility such as Chromix ColorThink Pro.

8.7.6 Averaging Measurement Files

Printing processes have many moving parts, and therefore often exhibit variability during a press run, for example between first and last sheet, and also variation within a printed sheet from left to right and top to bottom. Variations can occur in all printing systems including xerography, large format inkjet and within conventional processes such as offset, flexography and gravure printing.

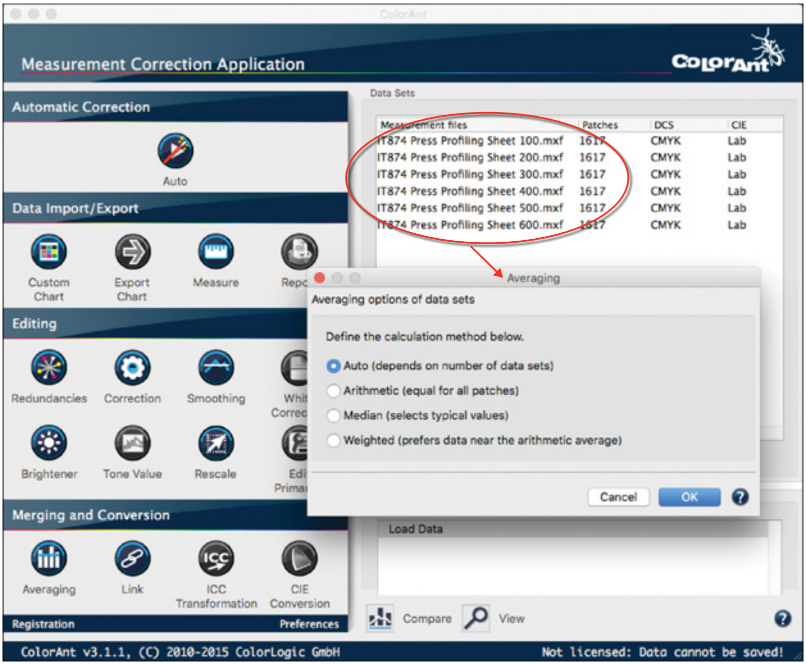
By printing and measuring a number of test charts and averaging the results, it is possible to minimize any color variations due to the printing process. Software such as ColorLogic's ColorAnt provides a clear interface with sophisticated averaging options including simple arithmetic mean, median, and weighted average, Figure 8.17. By averaging measurement files it is possible to make some allowance for the inevitable variations in real-life printing.

8.8 Making a Printer Profile

Once a print system has been calibrated and linearized, the test chart has been printed, and multiple measurements averaged, we are finally ready to make a printer profile. To make a printer profile a user would follow step-by-step instructions in a profiling program. Depending on the program being used there are a number of choices to make. The options most commonly encountered are GCR/UCR/black channel settings and a quality setting. Let's look at what these settings do.

8.8.1 Black Channel Generation

A major part of output profile generation involves a setting for black channel generation, incorporating processes known as Under Color Removal (UCR), Gray Component



ColorAnt
Measurement Correction Application
ColorAnt
Automatic Correction
Auto
Data Import/Export
Custom Chart
Export Chart
Measure
Repo
Editing
Redundancies
Correction
Smoothing
White Correc
Brightener
Tone Value
Rescale
Edit Prima
Merging and Conversion
Averaging
Link
ICC Transformation
CIE Conversion
Registration
Preferences
Data Sets
Load Data
Compare
View
ColorAnt v3.1.1, (C) 2010-2015 ColorLogic GmbH
Not licensed: Data cannot be saved!

Measurement files	Patches	DCS	CIE
IT874 Press Profiling Sheet 100.mxf	1617	CMYK	Lab
IT874 Press Profiling Sheet 200.mxf	1617	CMYK	Lab
IT874 Press Profiling Sheet 300.mxf	1617	CMYK	Lab
IT874 Press Profiling Sheet 400.mxf	1617	CMYK	Lab
IT874 Press Profiling Sheet 500.mxf	1617	CMYK	Lab
IT874 Press Profiling Sheet 600.mxf	1617	CMYK	Lab

Averaging

Averaging options of data sets

Define the calculation method below.

- ● Auto (depends on number of data sets)
- ○ Arithmetic (equal for all patches)
- ○ Median (selects typical values)
- ○ Weighted (prefers data near the arithmetic average)

Figure 8.17 ColorLogic's ColorAnt software allows the user to average data from different press sheets, based on different averaging options.

Replacement (GCR), and ink savings. All vendors offer a default setting for black generation, so for average requirements, it is possible to simply use the default values.

To understand this setting and how it affects the printed results, we consider the black channel generation process in more detail. Each printing ink controls a third of the spectrum; thus, cyan controls red, magenta controls green, and yellow controls blue. Theoretically, therefore the three printing inks have the whole spectrum covered and it is possible to reproduce all colors using only mixtures of cyan, magenta, and yellow ink. Most printing inks contain pigments or dyes that do not have perfect absorption spectra, the inks exhibit some unwanted secondary absorptions. When used together, therefore, cyan, magenta and yellow, create a muddy brown instead of a crisp, clean black. A fourth color in traditional printing is black, and although in theory this is not necessary, in practice it is used to provide a number of colorimetric and commercial advantages.

Because black is not strictly needed, its use provides a certain amount of redundancy. It is possible to create the same color using a lot of cyan, magenta, and yellow, and little black, or by using less cyan, magenta, yellow, and more black ink, as illustrated in Figure 8.18.

The GCR/UCR process is used to reduce the process colors (cyan, magenta, and yellow) and replace them with an "equivalent" amount of black ink.

The advantages of using a black component are illustrated in Figure 8.19, which compares a 3-channel image to a 4-channel image. Note the crisper, cleaner black in the shadows of the 4-color image compared to the dull, dirty black of the 3-channel image.

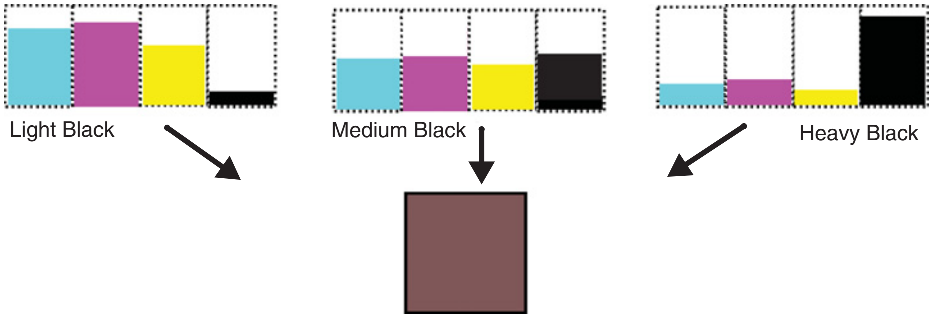


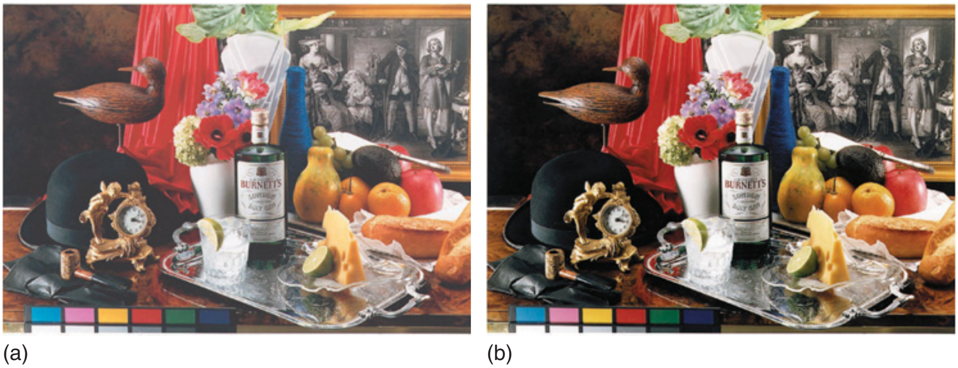
Figure 8.18 The same color can be made from C-M-Y and little black (left) or less C-M-Y and increased black ink (right). All different combinations are expected to create the same printed color.

Note too how the overall image quality and color reproduction appears better in the 4-color image.

The process of black replacement has a number of advantages. The use of lower amounts of colored ink make printing presses more stable because there is a lower level of colored inks and thus a minimization of their effects should the print density on press drift slightly. The use of black ink reduces the overall ink volume, which helps reducing drying time and enables printing on substrates such as newsprint. The use of cheaper black ink instead of expensive colored inks also reduces printing costs.

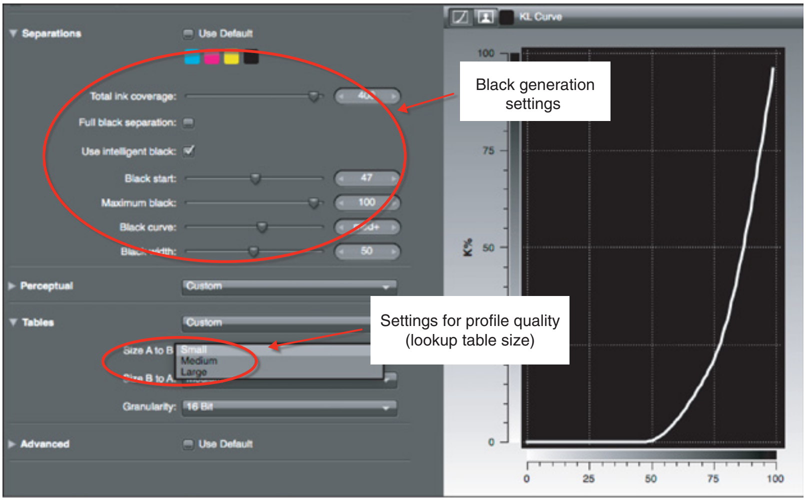
Color management software makes it possible for the user to select the level of black usage, as indicated in Figure 8.20. The black channel can be implemented in colored areas that have some common gray component or only in neutral gray colors. Different black channel strategies will change the ink make up, but should not affect the color of the final printed image.

The control of black generation can be described in terms of the maximum ink limit. The ink limit is specified as the sum of CMYK dot values for any pixel; thus the theoretical maximum limit for a 4-color process is 400% coverage. Web offset processes are especially prone to ink smearing, so the practical limit for web offset presses is around


(a)

(b)

Figure 8.19 (a) A 3-channel CMY image is compared to (b) a 4-channel CMYK image. Use of the black channel can improve the blacks and make the image cleaner and crisper. *Source:* FineEye Color Solutions. Reproduced with permission of FineEye Color Solutions.


Separations ☐ Use Default

Total ink coverage: 40

Full black separation: ☐

Use intelligent black: ☑

Black start: 47

Maximum black: 100

Black curve:

Black width: 50

Perceptual Custom

Tables Custom

Size A to B Small

Size B to A

Granularity: 16 Bit

Advanced ☐ Use Default

Black generation settings

Settings for profile quality (lookup table size)

Figure 8.20 X-Rite i1Profiler software allows the user to select black generation parameters (Separations) and lookup table size (Tables) during the profile generation process.

250%. SWOP specifications for magazines suggests a limit less than 300%, while SNAP specifications for newsprint only allow 200%–220% ink coverage.

An issue with printer profile generation is that the level of black replacement is fixed and cannot be easily changed. This is due to the fact that profile lookup tables are calculated with some fixed level of UCR/GCR. During making of the profile color management software asks the user to specify the amount of black required and creates a profile accordingly. If you want to change the black level you must start again from the measurement data file and re-create the profile using new black-generation parameters.

8.8.2 Profile Quality

When a printer profile is made, there is a user-selected software setting for quality measure, e.g. Small, Medium, and Large, Figure 8.20. This setting refers to the number of entries in the L*a*b* to CMYK and CMYK to L*a*b* lookup tables.

A printer profile lookup table does not store every L*a*b* value. If an image pixel contains an L*a*b* value of 12, 0, 0, the resulting CMYK will be "guessed" by using two neighboring L*a*b* values, which could be 10, 0, 0 and 20, 0, 0. The process of mathematically determining the missing value is called interpolation. If the spacing between values were reduced we would be interpolating between 10, 0, 0 and 15, 0, 0, which would increase the accuracy of the calculation. Thus, the accuracy of the interpolation (and hence the profile) increases as we have more data points. We have gone to so much trouble to calibrate our device, and print and measure a test chart that we must not reduce the profile's quality at this last step by making a small lookup table. The increased accuracy and smoothness of the transform is diagrammatically represented in Figure 8.21.

Increasing the number of entries in the lookup table improves accuracy but also increases the file size of the profile. Each lookup table is stored with different rendering intents, and thus an output profile might have a file size of 3 MB, which is not a huge

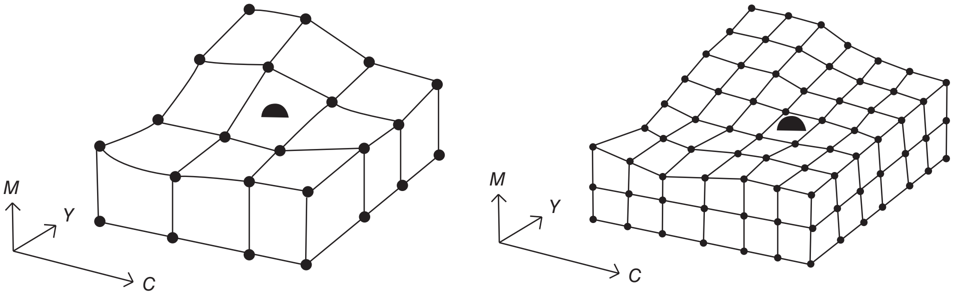


Figure 8.21 A lookup table uses the nearest neighbors on which to base the interpolation calculation, so having more grid points (right) improves the accuracy of the calculation – especially in areas where the underlying function is changing.

file size today. If file size is not an issue then it is recommended to use the largest number of cube nodes. If file size is an issue then it is possible to to reduce the size of the A to B (used only for proofing) lookup table, but retain the full size for the B to A lookup table, which is used to process final image data.

8.9 Checking the Printer Profile

Once a profile is created, it is useful to check it before leaving the profiling environment. Before distributing the profile to many users and prior to using the profile with live jobs, it is advisable to conduct quantitative (measurement-based) tests and qualitative, visual assessments. In this section we describe what these tests should evaluate and how to identify a "good" vs. a "bad" profile.

8.9.1 Quantitative Checking

Following profile generation, it is often useful to check the three-dimensional rendering of the lookup tables. Make sure there are no kinks or dents in the volume, Figure 8.22. If the gamut shape is not smooth in some areas, this could be due to an error in the chart-measurement process. Any strange distortions or discontinuities should be treated with suspicion.

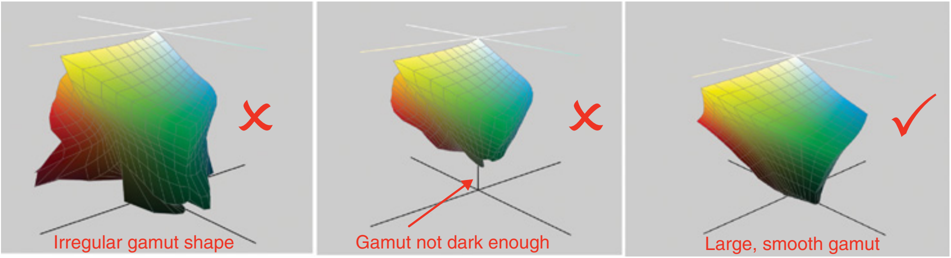


Figure 8.22 In an L*a*b* view, a printer profile gamut should not have an irregular shape (left) nor be too light (middle). A good output profile will have a large, regular gamut volume (right).

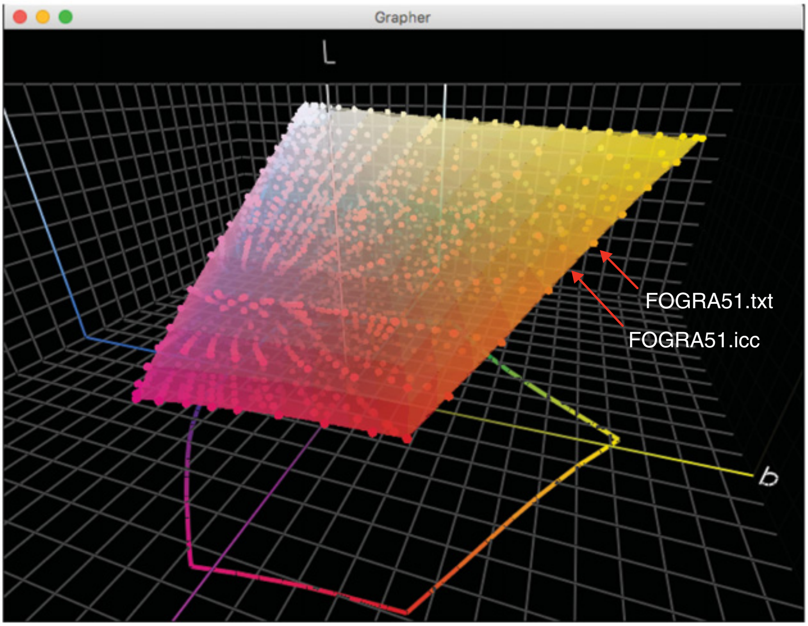


Figure 8.23 The FOGRA51 ICC profile gamut and the FOGRA51 measurement data are perfectly aligned, which provides confirmation of the profile generation process.

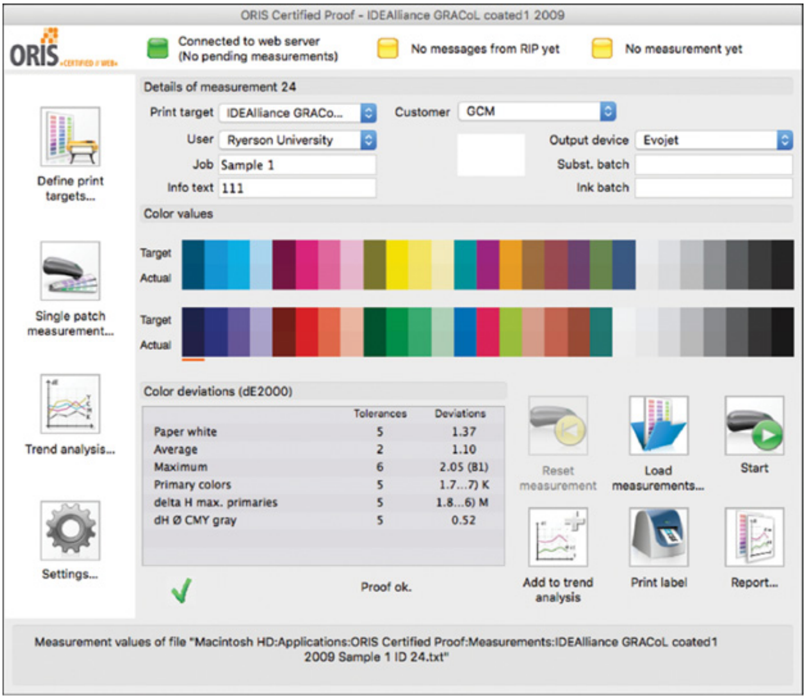
Look at the top and bottom of the gamut volume. The lower part of the volume should reach as low as possible, if the three-dimensional volume is suspended far above $L^* = 0$, this indicates that the system did not measure with a very dark black, and this will affect not only the black colors but could also negatively impact other colors in a printed image.

Using a utility such as Chromix ColorThink Pro it is possible to compare the data from the measurement file with the gamut indicated by the ICC profile, Figure 8.23. A profile is generated directly from the measurement data, so the two should closely align. The overlapping of these two items indicates a successful profiling process.

Perhaps the most fundamental, and comprehensive test, is to evaluate ΔE using a control strip. There are many parts of the process that can go wrong; perhaps a colleague changed the media without telling you, the test chart was not dry before it was measured, or a software setting was altered between printing the test chart and processing final images.

The performance of the printer profile can be checked using a control strip and this confirms that all parts of the color managed system are working as intended. CGS ORIS Certified // Web is a simple, elegant product for this purpose, Figure 8.24.

By measuring control strip test patches, it is possible to confirm if you are meeting your intended target to within some tolerance. Users can compute a ΔE check that is an all-encompassing metric, covering every aspect of the color management process including calibration, characterization and conversion. ΔE is a meaningful metric that can be readily quoted and widely understood. If you have an average ΔE of approximately 2, for 54 well chosen colors then you have a very robust, accurate, color-managed system.



ORIS Certified Proof - IDEAlliance GRACoL coated1 2009

Connected to web server (No pending measurements)

No messages from RIP yet

No measurement yet

Details of measurement 24

Print target: IDEAlliance GRACo...

Customer: GCM

User Ryerson University

Output device: Evojet

Job: Sample 1

Subst. batch:

Info text: 111

Ink batch:

Color deviations (dE2000)

	Tolerances	Deviations
Paper white	5	1.37
Average	2	1.10
Maximum	6	2.05 (B1)
Primary colors	5	1.7...7) K
delta H max. primaries	5	1.8...6) M
dH Ø CMY gray	5	0.52

✓ Proof ok.

Measurement values of file "Macintosh HD:Applications:ORIS Certified Proof:Measurements:IDEAlliance GRACoL coated1 2009 Sample 1 ID 24.txt"

Figure 8.24 CGS ORIS Certified // Web is a simple program that confirms "printing to the numbers." ΔE of less than 2, for 54 well chosen colors, indicates a very robust, accurate, color managed system.

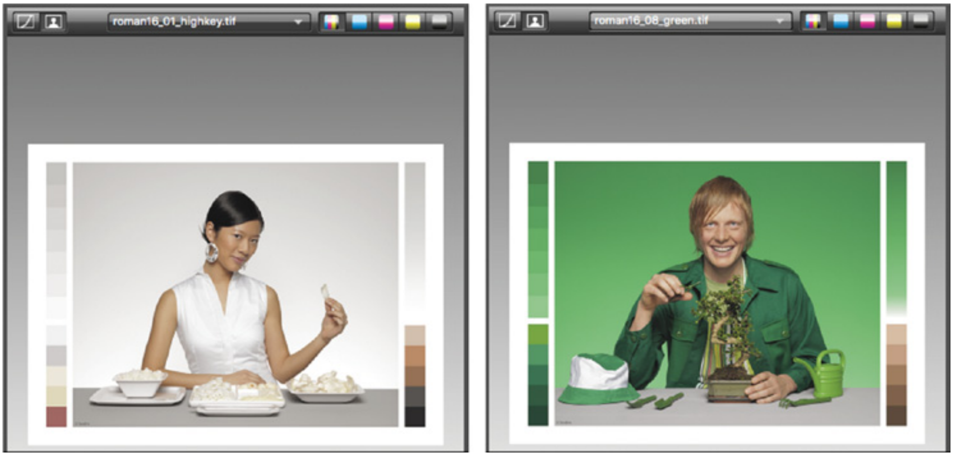
8.9.2 Qualitative Checking

Most profiling software will provide test images and tools that can be used to qualitatively assess the effect of the newly-generated profile on image data, an example of which is shown in Figure 8.25. It is also a good idea to process some images with the profile, print them, and evaluate them in a light booth.

Different images are likely to illustrate different issues. Therefore, it is recommended to use a range of images, such as high and low key, indoor scenes, outdoor scenes, human subjects, still life with memory colors, and so on, as shown in Figure 8.26. You should try and use images that are representative of your normal business. It is also useful to include an image with a vignette or other transition that can identify posterization and other artifacts.

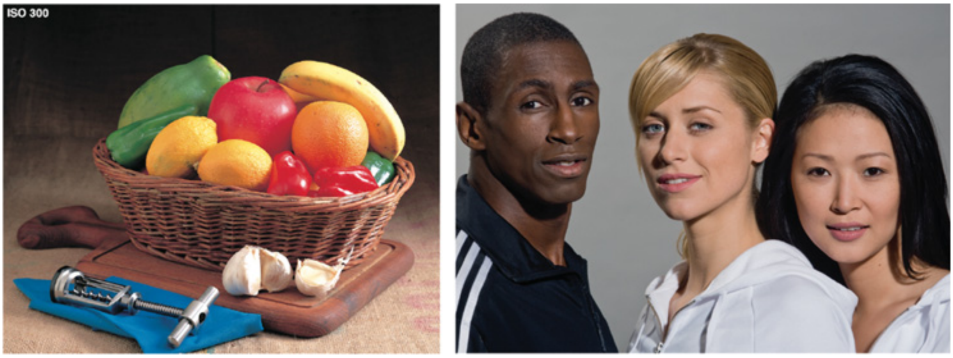
When looking at images, there are some key color concepts to consider, Figure 8.26. First, you should view the entire image. The overall contrast and color balance should be evaluated. Does the image contain a color cast that is noticeable? Are the grays neutral? Next, look closely at flesh tones. Look at the face of any people in the picture. It is very easy to see if a model appears "unwell" or appears yellow and jaundiced. Try to evaluate various skin colors, such as Caucasian, Hispanic, Asian, and African. The other category to check is memory colors; for example, the appearance of blue sky, green grass, or red apples. You should find the reproduction of these elements pleasing and evocative.

Finally, the highlights and shadows should be examined. Make sure there is gradation in both highlights and shadow regions. The gradient and patch set should show uniform



(a) (b)

Figure 8.25 X-Rite i1Profiler provides a pre-loaded set of test images to evaluate and verify the effect of the recently made profile.



(a) (b)

Figure 8.26 (a) A test image should contain memory colors such as a red apple or yellow banana and (b) different skin tones, including African-American, Caucasian and Asian. Image (a) *Source:* ©ISO 12640. Reproduced with permission of ISO 12640. Image (b) *Source:* GMG. Reproduced with permission of GMG.

gradation from patch to patch as the color darkens from zero to 100%. Are the highlights clean or do they have an unwanted color cast? Are the highlights blown out? Even though the highlights may be very faint in the less than 10% range, there should be some detail visible. The shadows should also be examined to see if they have "filled in." If the results look good, proceed with using this printer profile. If not, consider remaking the profile.

8.10 Reference Printing Conditions

It is often impractical to make a custom profile for an offset sheetfed or web press. Compared to an inkjet printer a printing press is a complicated device with many variables. The concept of reference printing conditions is based on the premise that, due to press variability, it is very difficult and often counter-productive to create a custom profile for each individual printing press and paper stock.

Instead of profiling each individual press and paper condition, there is a trend towards using generalized, averaged press conditions, called *reference printing conditions*. Reference printing conditions are data files that are widely used within the printing industry to represent the color characteristics of a printing press.

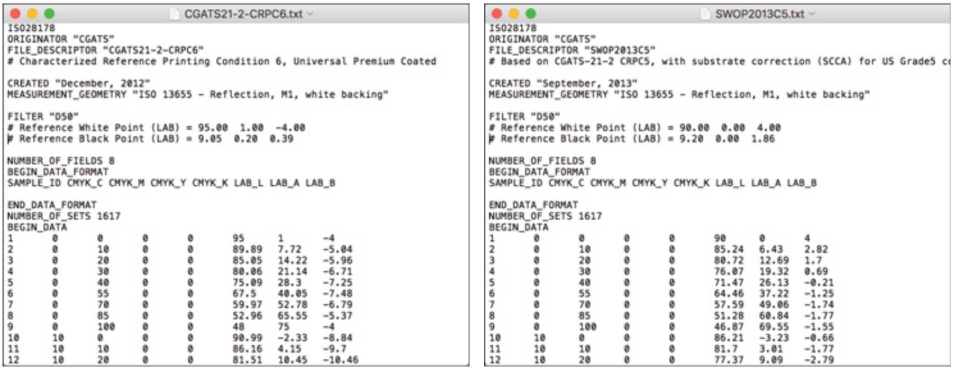
If the same paper, inks, and target densities are used, then it has been found that printing falls into distinct categories or "baskets," such as GRACoL and SWOP in North America and FOGRA51 in Europe. The newspaper industry has its own printing conditions, one of which is called SNAP. The North American specifications described so far – SNAP, GRACoL and SWOP – intentionally rhyme with the popular cereal jingle – snap, crackle and pop.

Data for reference printing conditions may be supplied by industry or national organizations such as Idealliance, Fogra, System Brunner or Japan's TC130 National Committee. Datasets are available as a free download from the ICC Characterization Data Registry at www.color.org. ICC profiles, made from these datasets, are readily available and pre-installed in software, such as Adobe Photoshop and prepress RIPs.

8.10.1 Developing Reference Printing Conditions

A reference printing condition is simply a characterization dataset – a measurement file containing CMYK and L*a*b* values of an IT8.7/4 printer chart for a particular press condition and substrate. The datasets embody the color characteristics of a printing process, so for example, note how in a SWOP (publication printing) dataset, the values are darker and less colorful than in a GRACoL dataset (commercial printing), Figure 8.27.

Committees of printers, print buyers, and suppliers collaborate to develop a reference printing condition. The datasets are developed based on practical press runs and thus represent results that can be achieved by the average print shop. In the US, industry groups such as SWOP and GRACoL, under the umbrella of Idealliance, conducted press runs starting in 1995, Figure 8.28.



```
IS028178
ORIGINATOR "CGATS"
FILE_DESCRIPTOR "CGATS21-2-CRPC6"
# Characterized Reference Printing Condition 6, Universal Premium Coated

CREATED "December, 2012"
MEASUREMENT_GEOMETRY "ISO 13655 - Reflection, M1, white backing"

FILTER "D50"
# Reference White Point (LAB) = 95.00  1.00  -4.00
# Reference Black Point (LAB) = 9.05  0.20  0.39

NUMBER_OF_FIELDS 8
BEGIN_DATA_FORMAT
SAMPLE_ID CMYK_C CMYK_M CMYK_Y CMYK_K LAB_L LAB_A LAB_B

END_DATA_FORMAT
NUMBER_OF_SETS 1617
BEGIN_DATA
1       0       0       0       0       95      1       -4
2       0       10      0       0       89.89   7.72    -5.04
3       0       20      0       0       85.05   14.22   -5.96
4       0       30      0       0       80.06   21.14   -6.71
5       0       40      0       0       75.09   28.3    -7.25
6       0       55      0       0       67.5    40.05   -7.48
7       0       70      0       0       59.97   52.78   -6.79
8       0       85      0       0       52.96   65.55   -5.37
9       0       100     0       0       48      75      -4
10      10      0       0       0       90.99   -2.33   -8.84
11      10      10      0       0       86.16   4.15    -9.7
12      10      20      0       0       81.51   10.45   -10.46
```

```
IS028178
ORIGINATOR "CGATS"
FILE_DESCRIPTOR "SWOP2013C5"
# Based on CGATS-21-2 CRPC5, with substrate correction (SCCA) for US Grade5 c

CREATED "September, 2013"
MEASUREMENT_GEOMETRY "ISO 13655 - Reflection, M1, white backing"

FILTER "D50"
# Reference White Point (LAB) = 90.00  0.00  4.00
# Reference Black Point (LAB) = 9.20  0.00  1.86

NUMBER_OF_FIELDS 8
BEGIN_DATA_FORMAT
SAMPLE_ID CMYK_C CMYK_M CMYK_Y CMYK_K LAB_L LAB_A LAB_B

END_DATA_FORMAT
NUMBER_OF_SETS 1617
BEGIN_DATA
1       0       0       0       0       90      0       4
2       0       10      0       0       85.24   6.43    2.82
3       0       20      0       0       80.72   12.69   1.7
4       0       30      0       0       76.07   19.32   0.69
5       0       40      0       0       71.47   26.13   -0.21
6       0       55      0       0       64.46   37.22   -1.25
7       0       70      0       0       57.59   49.06   -1.74
8       0       85      0       0       51.28   60.84   -1.77
9       0       100     0       0       46.87   69.55   -1.55
10      10      0       0       0       86.21   -3.23   -0.66
11      10      10      0       0       81.7    3.01    -1.77
12      10      20      0       0       77.37   9.09    -2.79
```

(a) (b)

Figure 8.27 Reference printing conditions for different printing processes are described by measurement files containing CMYK and L*a*b* values. Note how (a) CRPC6 (GRACoL) L*a*b* values are lighter compared to (b) SWOP data, as expected.

Figure 8.28 Don Hutcheson and Dick Presley at one of the early press runs to develop GRACoL and SWOP characterization data in the US. *Source:* Idealliance. Reproduced with permission of Idealliance.

The measurements from the first press runs were averaged and published as *Graphic Technology – Color Characterization Data for Type 1 Printing, ANSI CGATS TR 001-1995* and the data was referred to as "TR 001" data. This data is the first publicly available colorimetric characterization of a sheetfed offset printing press.

The characterization data files can be used to make an ICC profile. Profile making programs can create different perceptual rendering intents, different black generation strategies, and lookup tables of different sizes. This means that there can be many different ICC profiles for a given reference printing condition.

8.10.2 American and European Reference Printing Conditions

Reference printing conditions cover the full range of printing processes from heavy-weight catalog papers to newsprint. A number of reference printing conditions are offered by Idealliance and widely adopted in North America:

- GRACoL – on #1 coated sheet for commercial offset printing[2]
- SWOP #3 – for web offset publication printing on #3 grade sheet
- SWOP #5 – for web offset publication printing on #5 grade sheet

---

[2] Uses FOGRA39 as its basis.

The GRACoL (General Requirements for Applications in Commercial Offset Lithography) and SWOP (Specifications for Web Offset Publications) specifications do not use the M1 measurement condition and are superseded by the CRPC datasets, see below, however, as they are now well established and pre-loaded in many programs, such as Adobe Photoshop, their use is likely to continue for a number of years.

There are a number of reference printing conditions offered by Fogra (*Fo*rschung im *gra*fischen Gewerbe – the German Graphic Technology Research Association). The Fogra datasets are widely used in Europe and Australasia:

- FOGRA52 – sheetfed offset, uncoated paper
- FOGRA51 – sheetfed offset, premium coated sheet
- FOGRA48 – web offset, newsprint paper
- FOGRA39 – commercial offset, gloss or matt coated paper

The European Color Initiative (ECI) has made available ICC profiles that are based on reference print conditions:

- PSOuncoated_v3_FOGRA52.icc – based on dataset FOGRA52
- PSOcoated_v3.icc – based on dataset FOGRA51
- PSR_LWC_PLUS_V2_PT.icc – for process standard rotogravure (PSR) on light weight coated (LWC) stock

SNAP (Specifications for Newsprint Advertising Production) has published the following ICC profiles for newsprint:

- SNAP_220_2009.icc – for 220% total ink coverage
- SNAP_200_2.icc – for 200% total ink coverage

WAN-IFRA (World Association of Newspapers and News Publishers) has published the following ICC profile for newsprint:

- WAN-IFRAnewspaper26v5.icc – for 220% total ink coverage

Characterized Reference Printing Conditions (CRPC) are seven published datasets for small to large print gamuts. The family of the CRPC datasets are shown in Figure 8.29, where CRPC1 represents the smallest printing gamut and CRPC7 is for an extra large gamut printing process. The CRPC datasets provide consolidation, and duplication, of the North American datasets. In 2015, the CRPC datasets were controversially published as a Publicly Available Specification (PAS). The datasets are available as ISO/PAS 15339 and also as ANSI/CGATS datasets:

- CRPC1 – ColdsetNews – newsprint, small gamut printing
- CRPC2 – HeatsetNews – improved newsprint type paper
- CRPC3 – PremUncoated – utility printing on matt uncoated paper
- CRPC4 – SuperCal – general printing on super-calendared paper
- CRPC5 – PubCoated – typical publication printing
- CRPC6 – PremCoated – large gamut, typically commercial printing
- CRPC7 – Extra Large – extra large gamut printing process

There have been efforts to update all the above datasets to measurement mode M1, and the characterization data sets are routinely updated to better represent commonly available paper stocks for offset printing.

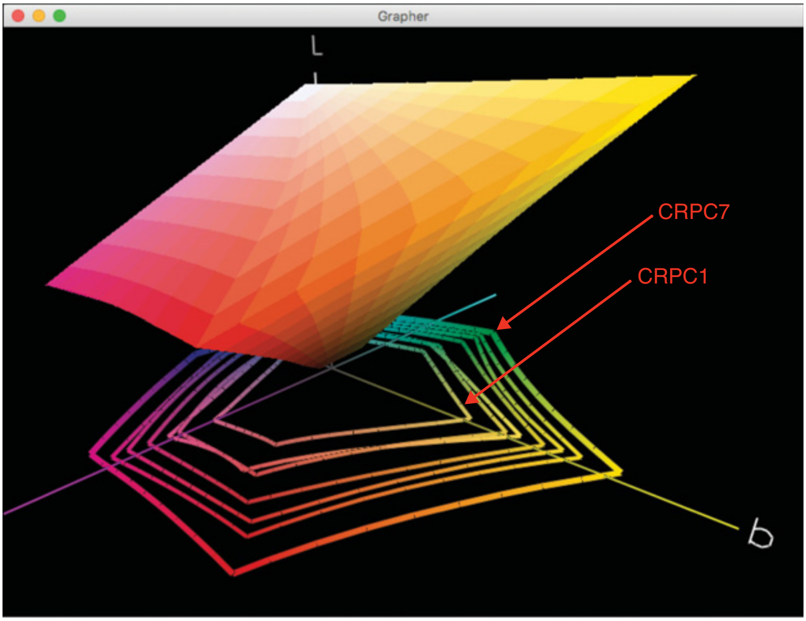


Figure 8.29 Characterized Reference Printing Conditions (CRPC1 – CRPC7) are datasets published for small to large print gamuts and can be visualized in a 3-D L*a*b* diagram.

8.10.3 Using Reference Printing Conditions in Prepress and Press

If a reference printing condition is chosen as a common color aim point, all parts of the process can aim for this target. Consider as an example the GRACoL reference print condition. A press is considered to meet the relevant reference printing condition if it uses appropriate ink and paper and can hit specific measurable print parameters. If the press room can achieve GRACoL target values we can assume the press is operating as a "GRACoL press" and the print job will exhibit GRACoL color characteristics. All parts of the workflow, from creative to layout and proofing and final production, can now assume and use a GRACoL ICC profile to describe the expected color response of the job. If the GRACoL printing condition is agreed upon between all parties, everybody is able to establish color expectations for the printed result.

In Photoshop, InDesign, or Illustrator, the creative professional can proof the design or image using a GRACoL profile. The user can preview the image in the GRACoL color space, Figure 8.30. The user can apply a gamut stain to see if any colors are out of gamut and the user can also make color edits based on the preview image. A full prediction of all aspects of the expected press result can be visualized in software.

The user may next like to produce a hardcopy proof of the image. The purpose of a proof is to simulate the visual characteristics of the final printed product. Within a proofing workflow, it is easy to create a hardcopy inkjet proof of the expected GRACoL press result. In a proofing workflow the RGB image would be processed via profiles in order to simulate the GRACoL response in a proof, Figure 8.31. The hardcopy proof

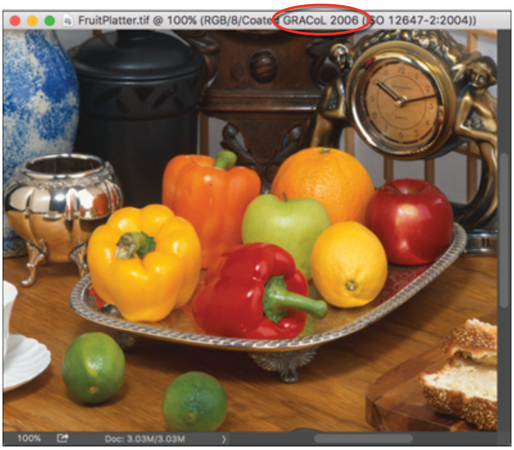
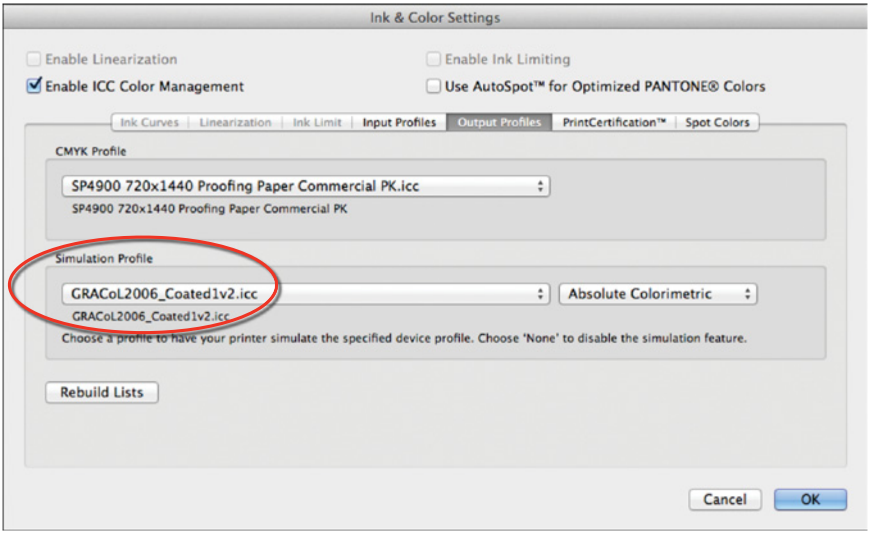

FruitPlatter.tif @ 100% (RGB/8/Coated GRACoL 2006 (ISO 12647-2:2004))
100%
Doc: 3.03M/3.03M

Figure 8.30 The GRACoL reference printing condition profile, can be used in Adobe Photoshop to preview image colors.

shows hows the image will appear when eventually printed on a press that is printing "according to GRACoL."

Consider printing on a digital press. Perhaps the customer requires a short run job, yet requests an offset "look and feel." It is easy to create the colors on a digital press that would be created during GRACoL offset printing. To do this the GRACoL ICC profile is selected as the source profile, Figure 8.32. To complete the color managed pairing the GRACoL profile is linked with a destination profile, the Xerox DocuColor 8000 device in this example.

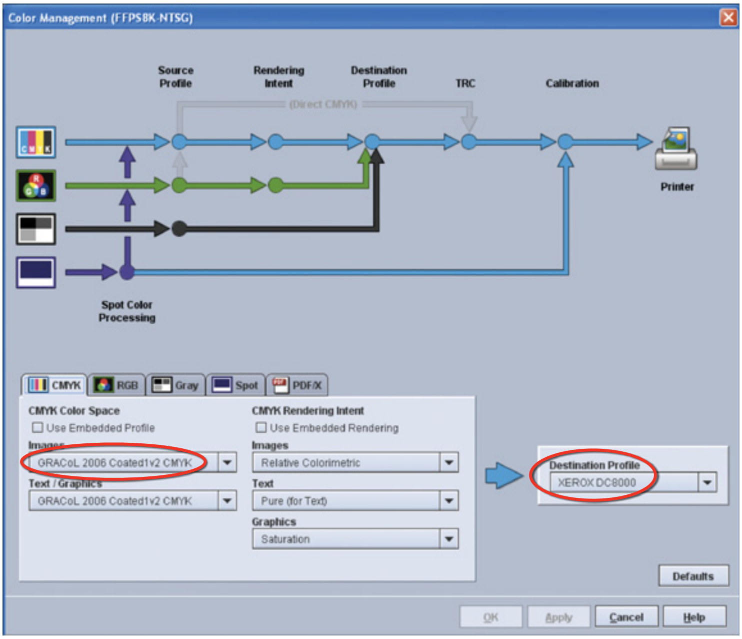

Ink & Color Settings
Ink Curves
Linearization
Ink Limit
Input Profiles
Output Profiles
PrintCertification™
Spot Colors
Rebuild Lists
Cancel
OK

☐ Enable Linearization
☑ Enable ICC Color Management
☐ Enable Ink Limiting
☐ Use AutoSpot™ for Optimized PANTONE® Colors

CMYK Profile
SP4900 720x1440 Proofing Paper Commercial PK.icc
SP4900 720x1440 Proofing Paper Commercial PK

Simulation Profile
GRACoL2006_Coated1v2.icc
Absolute Colorimetric
GRACoL2006_Coated1v2.icc
Choose a profile to have your printer simulate the specified device profile. Choose 'None' to disable the simulation feature.

Figure 8.31 In the ColorBurst RIP, the GRACoL profile is used as the press/simulation profile, and the result is proofed on an Epson Stylus Pro 4900 inkjet proofer (SP4900) with commercial proofing paper.



CMYK Color Space
☐ Use Embedded Profile
Images: GRACoL 2006 Coated1v2 CMYK
Text / Graphics: GRACoL 2006 Coated1v2 CMYK

CMYK Rendering Intent
☐ Use Embedded Rendering
Images: Relative Colorimetric
Text: Pure (for Text)
Graphics: Saturation

Destination Profile: XEROX DC8000

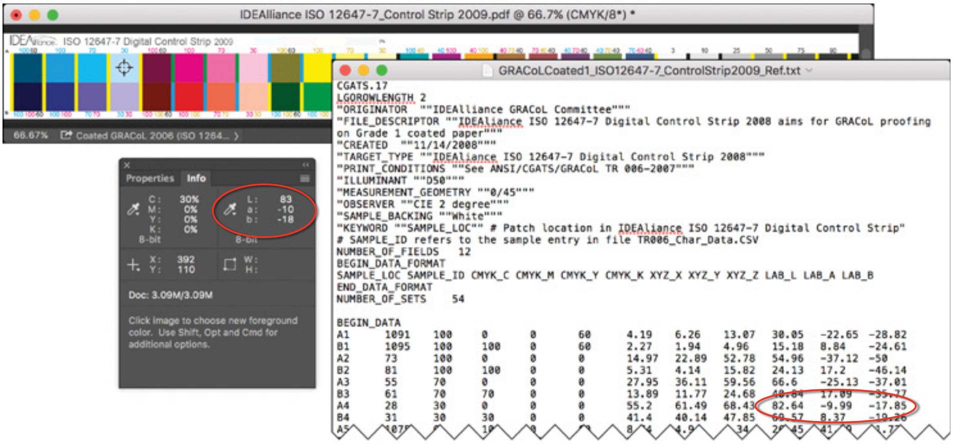
Figure 8.32 In Xerox FreeFlow Print Server, the GRACoL profile is the source profile and the local Xerox DocuColor 8000 device forms the destination.

The trend to use globally specified reference printing conditions helps printers that need to print in multiple markets, for example – a printer in Taiwan or Indonesia who has clients in Europe and also serves North American markets. Color communication is simplified by agreeing to one of the well defined reference printing conditions for the job. Reference printing conditions provide much greater independence between prepress and printing, allowing each more flexibility. And using ICC profiles for any of the print conditions enables realistic prepress and proofing, as the profiles indicate how the job is expected to be printed.

A color workflow based on an agreed reference printing condition is the recommended way of working as it is achievable, it creates a standardized look and feel for all jobs, it is easily verified, and the color expectation is easy to communicate to clients and print buyers.

8.10.4 "Printing to the Numbers"

Another way to think about reference printing conditions is in terms of "printing to the numbers." The numbers in this context are the L*a*b* values in a characterization data file for a given reference printing condition. One of the advantages of managing color using a reference printing condition is that there are readily available target L*a*b* values to aim for, and to use in verification. The concept is that if we hit the required L*a*b* numbers for some control patches, then we meet the reference printing condition and thus achieve the required color match.


IDEAlliance ISO 12647-7_Control Strip 2009.pdf @ 66.7% (CMYK/8*) *
ISO 12647-7 Digital Control Strip 2009
66.67%
Coated GRACoL 2006 (ISO 1264...)
Properties
Info
8-bit
Doc: 3.09M/3.09M
Click image to choose new foreground color. Use Shift, Opt and Cmd for additional options.
GRACoLCoated1_ISO12647-7_ControlStrip2009_Ref.txt

C: 30%
M: 0%
Y: 0%
K: 0%

L: 83
a: -10
b: -18

X: 392
Y: 110

W:
H:

```
CGATS.17
LGOROWLENGTH 2
"ORIGINATOR  ""IDEAlliance GRACoL Committee"""
"FILE_DESCRIPTOR ""IDEAliance ISO 12647-7 Digital Control Strip 2008 aims for GRACoL proofing
on Grade 1 coated paper"""
"CREATED  ""11/14/2008"""
"TARGET_TYPE ""IDEAliance ISO 12647-7 Digital Control Strip 2008"""
"PRINT_CONDITIONS ""See ANSI/CGATS/GRACoL TR 006-2007"""
"ILLUMINANT ""D50"""
"MEASUREMENT_GEOMETRY ""0/45"""
"OBSERVER ""CIE 2 degree"""
"SAMPLE_BACKING ""White"""
"KEYWORD ""SAMPLE_LOC"" # Patch location in IDEAliance ISO 12647-7 Digital Control Strip"
# SAMPLE_ID refers to the sample entry in file TR006_Char_Data.CSV
NUMBER_OF_FIELDS   12
BEGIN_DATA_FORMAT
SAMPLE_LOC SAMPLE_ID CMYK_C CMYK_M CMYK_Y CMYK_K XYZ_X XYZ_Y XYZ_Z LAB_L LAB_A LAB_B
END_DATA_FORMAT
NUMBER_OF_SETS    54

BEGIN_DATA
A1      1091    100     0       0       60      4.19    6.26    13.07   30.05   -22.65  -28.82
B1      1095    100     100     0       60      2.27    1.94    4.96    15.18   8.84    -24.61
A2      73      100     0       0       0       14.97   22.89   52.78   54.96   -37.12  -50
B2      81      100     100     0       0       5.31    4.14    15.82   24.13   17.2    -46.14
A3      55      70      0       0       0       27.95   36.11   59.56   66.6    -25.13  -37.01
B3      61      70      70      0       0       13.89   11.77   24.68   40.84   17.09   -35.77
A4      28      30      0       0       0       55.2    61.49   68.43   82.64   -9.99   -17.85
B4      31      30      30      0       0       41.4    40.14   47.85   69.57   8.37    -19.26
```

Figure 8.33 Adobe Photoshop can use the GRACoL profile and show predicted L*a*b* values which agree with the reference printing condition characterization data file.

Anybody can do this simple verification test anywhere in the process. If the company president is walking through the press room she can take a press sheet from the press stack and check the control bar to see if the patch values meet, for example, GRACoL.

Let us consider an example to illustrate practical "printing to the numbers." Consider the IDEAlliance Control Strip, Figure 8.33. If the CMYK values of this control strip were to be reproduced on a GRACoL print or proofing process, then the printed and measured values for each patch should be in accordance with the GRACoL characterization dataset. Photoshop allows us to use a GRACoL profile to confirm this process.

If a CMYK control strip is opened in Photoshop and the GRACoL profile is assigned to the control strip, Photoshop's Info palette shows us that the cyan patch of CMYK 30, 0, 0, 0, is expected to have an L*a*b* value of 83, −10, −18. And an examination of the GRACoL characterization data file we see that the expected L*a*b* value is 82.64, −9.99, −17.85. Photoshop's Info palette does not show decimal points, so the L*a*b* values are rounded, and with absolute colorimetric rendering in Photoshop's Color Settings we see excellent agreement between theory and practice. While the example considered a single cyan patch, usually the agreement with all the other patches of a control strip would be computed or even the full IT8.7/4 can be similarly verified.

The "printing to the numbers" verification can be used to answer some common questions in commercial printing. The following questions can arise – do you print to GRACoL, can you provide a SWOP proof, can your press meet FOGRA52? One of the advantages of managing color using a reference printing condition is that there is a simple way to answer these questions, by checking the numbers it is possible to confirm whether the process meets a reference printing condition or not.

Verification to the numbers is a very simple process to do with a very significant result – if the numbers match, the colors will match. For this reason, matching a reference printing condition is part of all color certification and validation programs in the US and Germany. The "printing to the numbers" check is used in programs such as Fogra Process Standard Digital (PSD) or Idealliance Digital Press and Inkjet Certification programs.

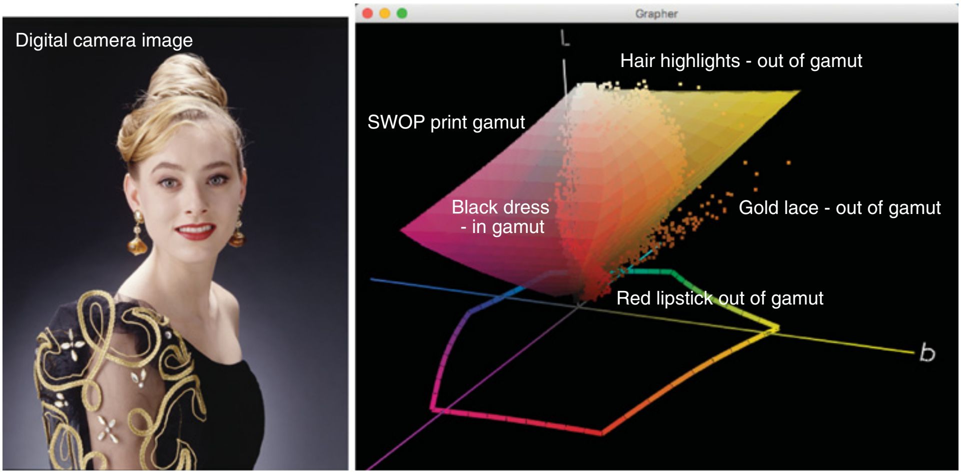


Figure 8.34 The black dress and neutral background in this digital camera image are in gamut, but some hair highlights, gold lace and red lipstick are out of the SWOP print gamut.

8.11 Rendering Intents

An important topic in printer profiles is the concept of rendering intents. Rendering intents are relevant to all parts of an ICC workflow, but are particularly important during printing because this is typically where the image will often be going from a device with a larger color gamut (digital camera) to a smaller gamut (press).

In Figure 8.34 we can see that some colors in an image from a digital camera are out of gamut of the intended press condition. The black dress and the neutral background are in gamut and can be reproduced accurately, but the red lipstick, some of the gold lace, and some of the very light colored hair of the model are out of gamut of the SWOP print process.

When we cannot print a particular color, selecting different rendering intents allows the user to control how the system finds an alternative by “pulling” out of gamut colors into gamut. Color management systems can be directed to use different approaches to deal with colors that are out of gamut. The different methods are called *rendering intents*.

The ICC supports four rendering intents: perceptual, relative colorimetric, absolute colorimetric, and saturation. The intents are related to gamut compression techniques. Figure 8.35 is a horizontal slice through the L*a*b* color space volume and shows how the rendering intents deal with out of gamut colors. The perceptual intent compresses the whole larger gamut so that it fits into the smaller gamut. The colorimetric intents clip out of gamut colors, and the saturation intent expands in-gamut colors to fill the available gamut shape.

Different rendering intents may be chosen for different images and different situations. There are general rules as to which intent to use with which image type, but there is no hard and fast rule, and the most appropriate rendering intent could be decided on an image-wise basis. A photographer, for example, hoping to retain the color balance and overall impression of a photograph from digital camera to printer, would probably use the perceptual or relative colorimetric rendering intent, while a prepress operator

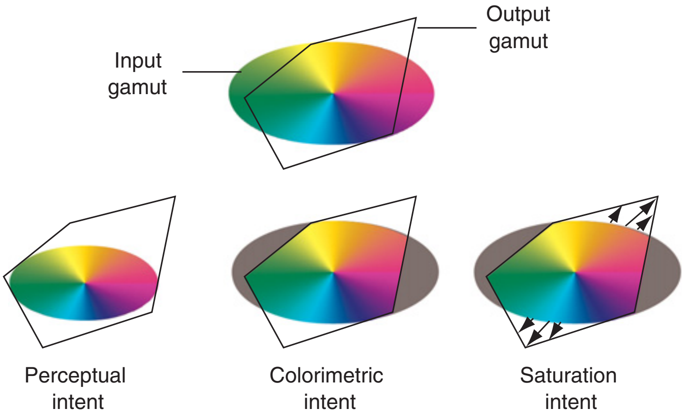


Figure 8.35 This figure shows a horizontal slice through the L*a*b* color space. The ICC supports different rendering intents that can have a different effect on image colors as we transform them from input to output color space.

seeking to create an inkjet proof of a press sheet would use the absolute colorimetric intent.

Some image pathways will use more than one rendering intent. For example, in soft proofing and press proofing we may want to transform the image to the printer space using perceptual rendering, but for viewing, the image would be returned to the profile connection space using relative or absolute colorimetry.

8.11.1 Perceptual Rendering Intent

Perceptual intent is used for photographic-type images. The object of this intent is to process images to achieve a pleasing result. A pleasing result is most often obtained if we do not distort the relationship between colors. If two colors in Figure 8.35 are close together in the original and a third is further away, following perceptual compression, the two colors are still relatively close together and the third is still further away. Thus the colors themselves have changed, but their relationship to each other remains the same.

The perceptual intent does a number of useful things. It brings out-of-gamut colors into gamut while maintaining a distinction between the colors. In perceptual rendering the gamut of the destination device is fully utilized, which is always a good thing.

Perceptual rendering does not give the most accurate rendition of the original and may change colors – even if the colors are within the gamut of the destination device. However, this is not a problem. In most cases, for example in an image printed in a magazine, we are not doing a side-by-side comparison, so there is no requirement to match the color of the original, but only to create a pleasing reproduction.

The ICC does not define the precise mechanism for perceptual mapping. Each profiling vendor is free to provide a mapping of colors that they think creates the most pleasing rendition and will be most suitable for their user base. Each manufacturer has their own view on the best way to render pictures of the new baby, indoor flash birthday parties, holiday beach scenes, etc. so you will get different results with each vendor's perceptual intent.

There are some situations where the perceptual intent is less favored today. If a colorful image has many points outside the printer gamut, then perceptual rendering is OK. But perceptual rendering will compress both a colorful image and a less-colorful image by the same amount. This is because the perceptual lookup table is fixed and is unaware that a less-colorful image does not need any compression to fit within the gamut of the output device. It is interesting to note that the Windows WCS system is superior in this sense as it uses a "smart CMM" that is able to direct conversions dynamically, according to image content, and would therefore be able to differentiate between large and small gamut input images. For this reason, in an ICC architecture, if there is not much data outside the printer gamut, in other words if the source and destination gamuts are of similar size, then instead of perceptual rendering, relative colorimetry will probably produce a better result.

8.11.2 Relative Colorimetric Rendering Intent

When using the relative colorimetric intent, colors that are within the gamut of both the source and destination space are reproduced with no change. The colorimetric intent would be used for exact color reproduction, such as in the case of in-gamut, logo colors. Relative colorimetry is also used for images, when the source and destination gamuts are of similar size.

In absolute and relative colorimetric rendering, colors that are outside the gamut of the destination process are clipped and forced to the gamut boundary, Figure 8.35. As more than one color in the original can be mapped to the gamut edge many colors can become one color, which means that colors that were distinct in the original may be indistinguishable in the reproduction.

There are two versions of the colorimetric intent, relative colorimetric and absolute colorimetric. These intents are generally similar, but with an important difference relating to the white point of the substrate.

Consider an example in which an image of a lily, with white highlights is reproduced on yellow paper and blue paper, Figure 8.36. If the image is printed using relative colorimetry, the highlights in the image follow the color of the substrate. In this example, the highlights in the original have no ink, so the highlights in the reproductions will also have no ink. The highlights in the reproduction will therefore take on the color of the paper. The yellow substrate will turn the lily yellow and the blue stock will turn the lily blue. (Due to chromatic adaptation, when viewing these images on their own, our

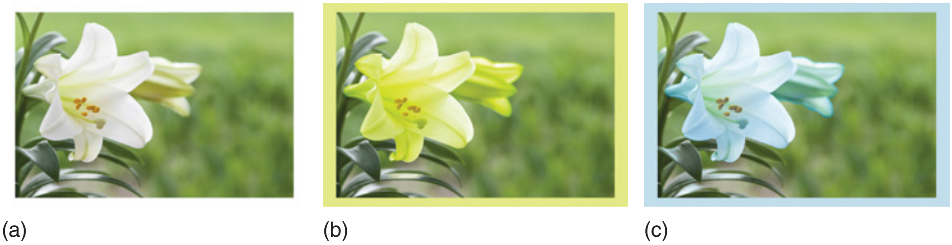

(a) (b) (c)

Figure 8.36 When using relative colorimetry, (a) the original image highlights take on the color of the paper, becoming (b) yellow or (c) blue. *Source:* ©hookmedia/Adobe Stock.

eye adjusts to the white point in each reproduction and the lily will eventually appear "white" in either reproduction.)

Relative colorimetry takes into account the white point of the destination substrate and displays/prints the image relative to the new white point. Relative colorimetry maps the white of the source to the white of the destination and adjusts other colors accordingly.

To summarize, we can say that in relative colorimetry the original and the reproduction are each displayed *relative to the white points of their respective substrates*. This intent is most suitable where we are trying to get a close (but not exact or side-by-side) match between original and reproduction, the source and destination devices have similar size gamuts, and we are using substrates that are not too colored. Relative colorimetry is a good choice for many types of photographic images.

8.11.3 Absolute Colorimetric Rendering Intent

Logo colors that need to be exact are reproduced with the absolute colorimetric intent. Press proofing is also done using the absolute colorimetric intent.

Absolute colorimetry is similar to relative colorimetry except that in absolute colorimetry the white point does not change from source to destination. The absolute colorimetric intent creates exactly the colors that were in the original (where possible). Thus if the original had a yellowish highlight, the absolute colorimetric intent would ensure that the reproduction has a yellowish highlight, too, as shown in Figure 8.37. The absolute intent would place ink down in the highlight areas of the reproduction to ensure that the ink and paper color create a yellowish white. Of course the color management process ensures all other colors in the image are also an exact match to the original. *In absolute colorimetry, all colors in the reproduction are, where possible, an exact match to the original irrespective of the substrate color.*

A printing press uses paper that has a very different base than inkjet paper and may be warmer (more yellow) than blueish proofing paper. The absolute colorimetric intent will create the yellow look of the press in the clear areas of the inkjet paper using an appropriate amount of yellow ink.

Absolute colorimetry is used in proofing scenarios where we would like to simulate the output of one printer on a second device and do a *side-by-side* comparison. The

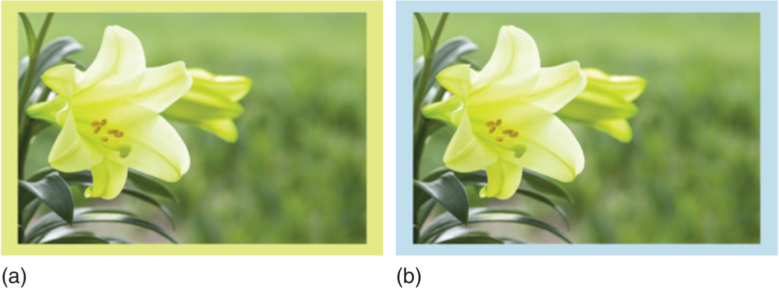

(a) (b)

Figure 8.37 In absolute colorimetry the white point in the image is not allowed to change, so (a) a yellow press image is still yellow even on (b) blue proofing paper.

image is reproduced exactly as the original. Absolute colorimetry is used for accurate side-by-side comparisons, such as in press proofing.

In order for absolute colorimetry to work the proofing stock must be lighter than the press sheet it is trying to simulate, so it can accommodate the small amount of ink needed to stain the highlights.

The absolute and relative colorimetric intents are not confined to printer profiles and are used in other profile types, including monitor profiles.

8.11.4 Saturation Rendering Intent

Saturation moves in-gamut colors toward the edge of the destination gamut for maximum impact, Figure 8.35. This intent is used to create business graphics in which the goal is to create colorful and vibrant images with no interest in the specific color, per se.

8.12 Device Link Workflows

Device link profiles are commonly used in a printing workflow to create, for example, a CMYK-to-CMYK color transformation. A device link profile provides a convenient shortcut, so if you know you always want to use two devices (for example, from one CMYK press to another CMYK press), you can combine the two profiles into a single device link profile. A device link profile is an ICC-approved profile type.

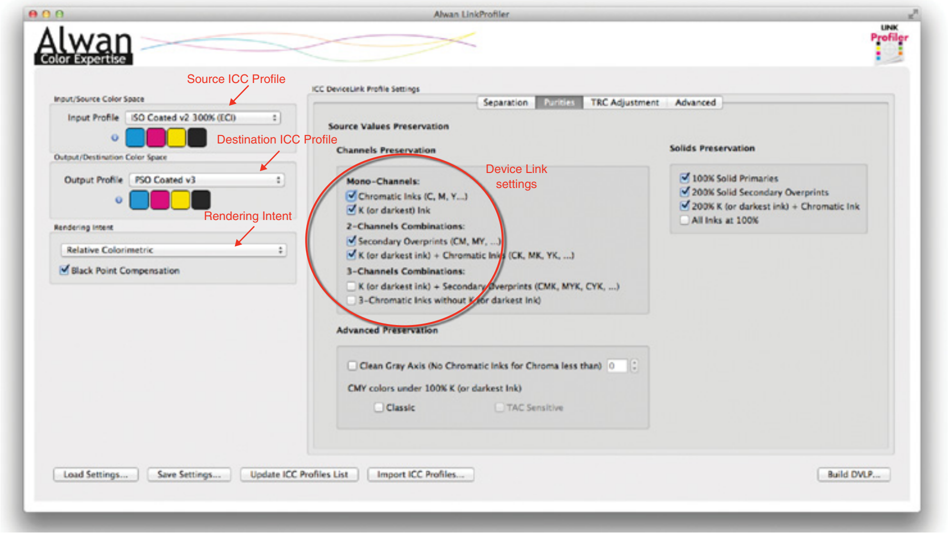
In this section we consider a product, Alwan LinkProfiler, that can be used to create a device link profile from two source profiles. We also consider GMG ColorProof that uses a device link configuration but in an non-ICC, proprietary, configuration.

8.12.1 ICC Device Linking

Device link profiles are an approved ICC profile type that can be used for fixed, device to device color conversions. A device link ICC profile allows, for example, an RGB to CMYK or a CMYK to CMYK color transformation. Device link profiles are made from concatenating together a source and destination profile into a single device link profile, Figure 8.38.

A common scenario for use of a device link profile is when a CMYK file for a press must be converted to the CMYK color space for an inkjet proofer. Another common use of device link profiles is when it is necessary to direct a CMYK file from its original press destination to a different CMYK destination, perhaps from an offset press to a digital press, or offset press to newsprint, etc.

To generate a device link profile, two profiles are presented to a software product that supports device link profile generation. A well known program is Alwan LinkProfiler, Figure 8.38. LinkProfiler takes the source and destination profile, and with user-directed settings, combines the profiles into a single profile. The concatenation process uses the L*a*b* profile connection space to create a device link lookup table, but after that, information relating to the L*a*b* connection space is no longer retained. In other words, device link profiles convert color directly from one color space to another color space, without the use of an intermediate conversion to L*a*b*.



Source ICC Profile

Destination ICC Profile

Rendering Intent

Device Link settings

Input/Source Color Space

Input Profile: ISO Coated v2 300% (ECI)

Output/Destination Color Space

Output Profile: PSO Coated v3

Rendering Intent

Relative Colorimetric

☑ Black Point Compensation

ICC DeviceLink Profile Settings

Source Values Preservation

Channels Preservation

Mono-Channels:
☑ Chromatic Inks (C, M, Y...)
☑ K (or darkest) Ink

2-Channels Combinations:
☑ Secondary Overprints (CM, MY, ...)
☑ K (or darkest ink) + Chromatic Inks (CK, MK, YK, ...)

3-Channels Combinations:
☐ K (or darkest ink) + Secondary Overprints (CMK, MYK, CYK, ...)
☐ 3-Chromatic Inks without K (or darkest Ink)

Solids Preservation
☑ 100% Solid Primaries
☑ 200% Solid Secondary Overprints
☑ 200% K (or darkest ink) + Chromatic Ink
☐ All Inks at 100%

Advanced Preservation
☐ Clean Gray Axis (No Chromatic Inks for Chroma less than) 0

CMY colors under 100% K (or darkest Ink)
☐ Classic
☐ TAC Sensitive

Figure 8.38 Alwan LinkProfiler creates a new device link CMYK–CMYK ICC profile from a source and destination profile.

Some of the advantages of a device link profile are that it is possible to preserve the black channel so that black text, tints, and solids are maintained, thus a 100% black stays 100% black and any text in the graphics is not changed to a 4-color black. A device link profile can retain the purity and protect the primary colors – CMYK, and secondary printed colors – RGB.

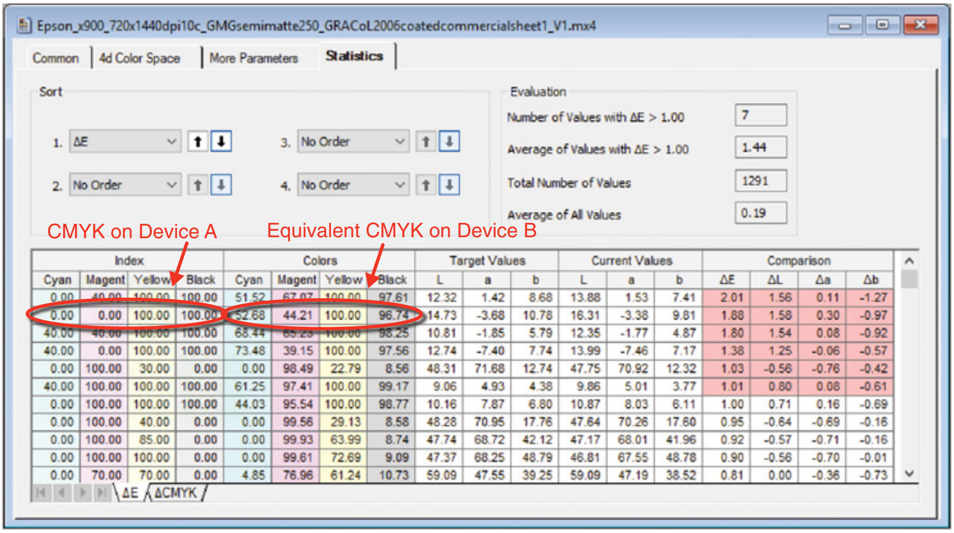
During creation of a device link profile there is the opportunity to introduce ink savings using a UCR/GCR process. Other advantages of a device link workflow are that profile conversion settings can be applied by a skilled prepress supervisor which removes the risk of a wrong choice by a less-skilled operator. A device link profile saves time as an operator does not have to work through many menu selections at run time.

The disadvantages of a device link transform are that device link profiles are not as flexible as individual ICC profiles. A device link profile can only be used for a conversion between two specific device color spaces; we can think of this as a "hard-wired" pair of profiles. Another limitation of a device link profile is that the rendering intent cannot be changed; the rendering intent is "baked in" at the time the device link profile was created.

After an ICC device link profile has been made in Alwan LinkProfiler we could use it in any ICC workflow. There are many instances where device link profiles are very useful in real world color management. Adobe Photoshop, now supports device link profiles. Most RIPs, servers, and other workflow systems also support device linking.

8.12.2 Proprietary Device Linking

GMG ColorProof is a well established color proofing solution used to create highly-accurate, contract color proofs, Figure 8.39. ColorProof is a non-ICC, proprietary



Evaluation

Number of Values with ΔE > 1.00: 7
Average of Values with ΔE > 1.00: 1.44
Total Number of Values: 1291
Average of All Values: 0.19

CMYK on Device A

Equivalent CMYK on Device B

Index				Colors				Target Values			Current Values			Comparison			
Cyan	Magent	Yellow	Black	Cyan	Magent	Yellow	Black	L	a	b	L	a	b	ΔE	ΔL	Δa	Δb
0.00	40.00	100.00	100.00	51.52	67.07	100.00	97.61	12.32	1.42	8.68	13.88	1.53	7.41	2.01	1.56	0.11	-1.27
0.00	0.00	100.00	100.00	52.68	44.21	100.00	96.74	14.73	-3.68	10.78	16.31	-3.38	9.81	1.88	1.58	0.30	-0.97
40.00	40.00	100.00	100.00	68.44	65.23	100.00	98.25	10.81	-1.85	5.79	12.35	-1.77	4.87	1.80	1.54	0.08	-0.92
40.00	0.00	100.00	100.00	73.48	39.15	100.00	97.56	12.74	-7.40	7.74	13.99	-7.46	7.17	1.38	1.25	-0.06	-0.57
0.00	100.00	30.00	0.00	0.00	98.49	22.79	8.56	48.31	71.68	12.74	47.75	70.92	12.32	1.03	-0.56	-0.76	-0.42
40.00	100.00	100.00	100.00	61.25	97.41	100.00	99.17	9.06	4.93	4.38	9.86	5.01	3.77	1.01	0.80	0.08	-0.61
0.00	100.00	100.00	100.00	44.03	95.54	100.00	98.77	10.16	7.87	6.80	10.87	8.03	6.11	1.00	0.71	0.16	-0.69
0.00	100.00	40.00	0.00	0.00	99.56	29.13	8.58	48.28	70.95	17.76	47.64	70.26	17.60	0.95	-0.64	-0.69	-0.16
0.00	100.00	85.00	0.00	0.00	99.93	63.99	8.74	47.74	68.72	42.12	47.17	68.01	41.96	0.92	-0.57	-0.71	-0.16
0.00	100.00	100.00	0.00	0.00	99.61	72.69	9.09	47.37	68.25	48.79	46.81	67.55	48.78	0.90	-0.56	-0.70	-0.01
0.00	70.00	70.00	0.00	4.85	76.96	61.24	10.73	59.09	47.55	39.25	59.09	47.19	38.52	0.81	0.00	-0.36	-0.73

Figure 8.39 GMG ColorProof uses a lookup table to match the output of Device A on Device B. The colors on device A can be created on device B, but with different CMYK values.

solution that incorporates the essence and concepts of managing color using a device link approach.

ColorProof uses a lookup table to link two specific printing processes. Images destined for the original CMYK process can be remapped to create the same printed color on the new device. To create the mapping a test chart, perhaps the IT8.7/4, is printed on CMYK Device A and CMYK Device B. The two charts are measured and presented to the software program. GMG ColorProof uses L*a*b* measurements to iteratively create a CMYK–CMYK lookup table as shown in Figure 8.39. Suppose the CMYK value in an image destined for Device A is 0, 0, 100, 100, the same color could be created on Device B with CMYK of 53, 44, 100, 97. The CMYK value would be “looked up” using this CMYK–CMYK lookup table.

8.13 Process Control in Printing

One of the basic premises of ICC-based color management is that the printing system must be stable and repeatable in order that conditions during profile generation are still in play when the profile is applied and used to print the job. Device stability is monitored via process control, and this aspect is so important in press color management that the three Cs of color management are often extended as follows – calibration, characterization, conversion and process *control*.

Depending on the type of printing process there are many causes for variability. Digital presses are very susceptible to variability in the environmental conditions including the temperature and humidity, both of the room and of the media. In gravure printing it is necessary to consider the cylinder engraving, ink chemistry, doctor blades, impression roller, electrostatic assist, paper grade, and other factors. The offset printing process is very fast, so conditions must stay stable with printing at up to 12,000 sheets/hour. The press sheet area is also large, so there is a requirement for uniform inking over a press sheet that can typically be 40" wide.

Another variable in the pressroom is the press operator. Operators sometimes ignore instructions to "print to the numbers". Part of the problem is convincing the operator to adhere to some standard settings and not seek to "improve" the color reproduction.

It can be seen that there are many physical, mechanical, environmental, and human variables that can all introduce variation in the print process. For successful color management it is important to ensure that all parts of the process that contribute to the final result are monitored and controlled. It is a well established management mantra that to manage a process it must be measured and monitored, and the same applies here; to manage a color print process color must be measured and monitored. Let us look at some of the methods that can be used to measure and monitor color during printing.

One consideration in printing with a large sheet size, is ink application across the sheet. It is important to have consistent and uniform ink application across the full width of the sheet. Control elements can be used, such as repeating CMYK patches, these patches can be measured using a scanning spectrophotometer to evaluate ink uniformity, Figure 8.40.

To monitor print quality on a digital press users can print a quality control document, an example of which is shown in Figure 8.41. This example includes control patches,

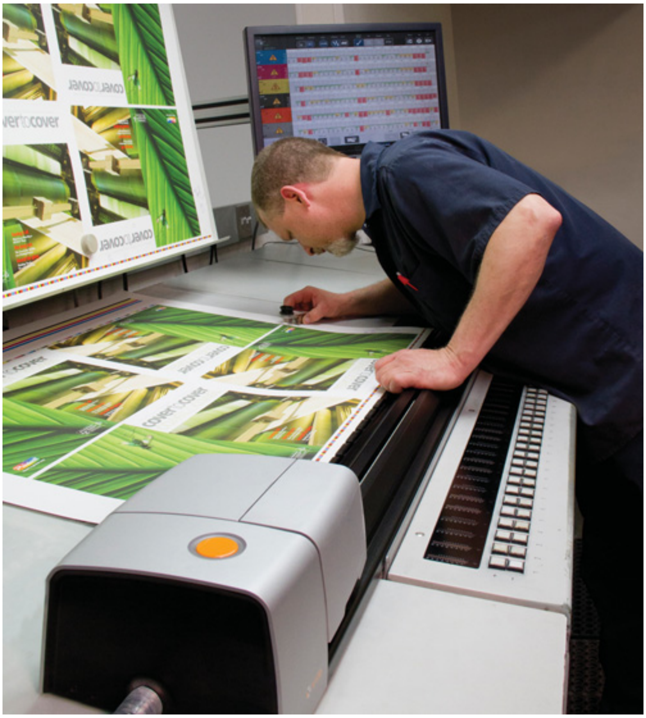


Figure 8.40 Process control is achieved by measuring control patches along the edge of a press sheet using the X-Rite Intellitrax system. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

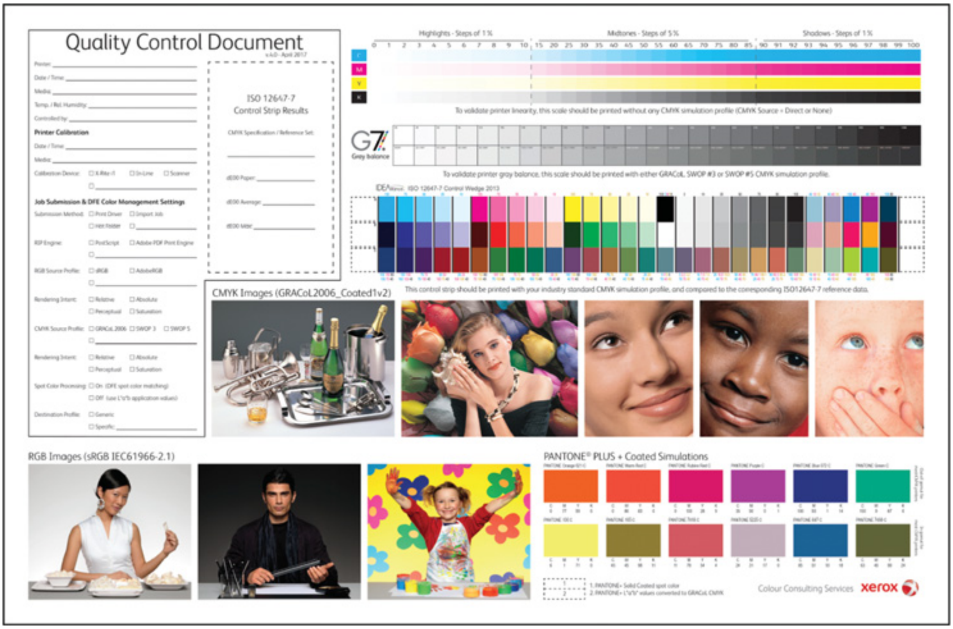

Quality Control Document
ISO 12647-7
Control Strip Results
G7
CMYK Images (GRACoL2006_Coated1v2)
RGB Images (sRGB IEC61966-2.1)
PANTONE® PLUS + Coated Simulations
Colour Consulting Services
xerox

Figure 8.41 The Xerox Quality Control Document contains a number of relevant test items including RGB and CMYK images, control patches, and spot color items. The document can be printed periodically to monitor color performance on a digital press. *Source:* Xerox. Reproduced with permission of Xerox Canada.

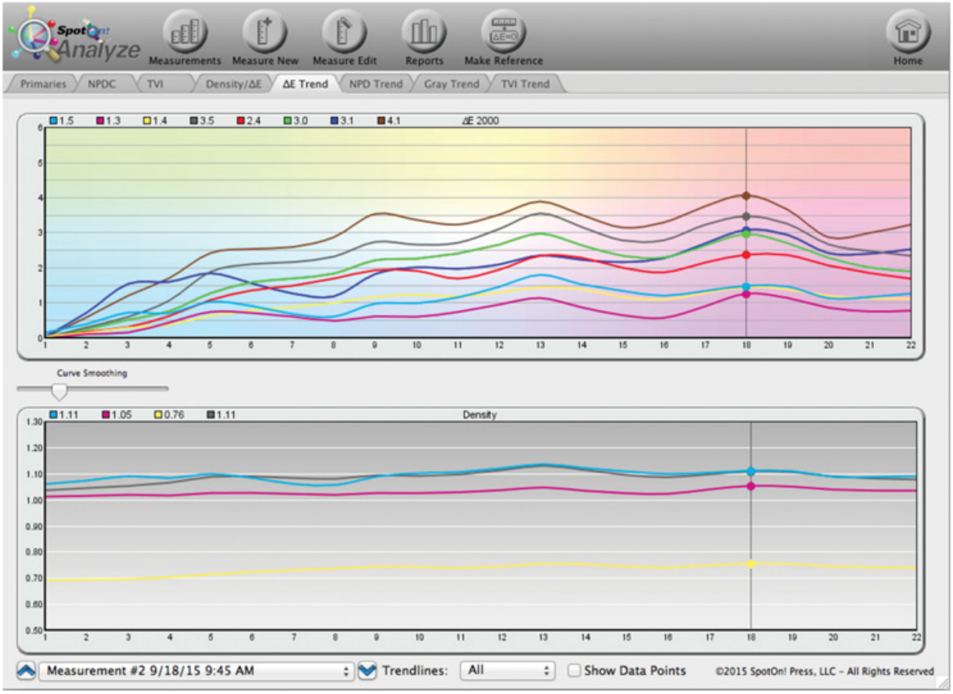
CMYK ramps, gray balance patches, and images with skin tones that offer a good basis for comparison. Users should print this document on a regular basis and after any major upgrade or equipment change.

There are many dedicated software programs that can capture measurements directly from a spectrophotometer. Spot On! Analyze is an example of a dedicated process control tool that can be used to evaluate many different forms of printing, Figure 8.42.

The Spot On! Analyze report shows variation of the device being tracked over a period of time. Measuring and recording the device behavior allows us to monitor any change in performance. Evaluation with a trend line allows us to evaluate if the device is out of tolerance or if the device is tending to drift out of tolerance. The graph provides data that allows analysis of causes for instability, e.g. during a particular shift or after the weekend when a machine was not in use.

In a professional production environment regular measurement and monitoring procedures should be established. The data ensures the systems are operating as intended which guarantees a quality printed product. Trending data is a powerful tool that can be mined to improve productivity and identify sources of error. Without continuous color measurement and monitoring a job could be printed with bad color leading to a reprint, lost profits and a tarnished reputation.

Process monitoring is not so critical in displays and digital cameras as those imaging systems have less moving parts and relatively stable operating conditions. Process control in print color management is mandatory for color management to work.


SpotOn! Analyze
Measurements
Measure New
Measure Edit
Reports
Make Reference
Home
Primaries
NPDC
TVI
Density/ΔE
ΔE Trend
NPD Trend
Gray Trend
TVI Trend
1.5
1.3
1.4
3.5
2.4
3.0
3.1
4.1
ΔE 2000
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Curve Smoothing
1.11
1.05
0.76
1.11
Density
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
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22
©2015 SpotOn! Press, LLC – All Rights Reserved

Measurement #2 9/18/15 9:45 AM

Trendlines: All

☐ Show Data Points

Figure 8.42 SpotOn! Analyze is a software tool that gathers press data and displays trend lines to show variation of each device over a period of time.

8.14 Summary

This chapter started with the first C of color management – calibration. A number of calibration concepts were described including ink hooking for inkjet devices and paper calibration for digital presses. The section on calibration for offset printing described the G7 calibration procedure.

A number of printer test charts were reviewed, and it was shown that the IT8.7/4 test chart is now widely accepted and as the number of patches has been increased compared to the IT8.7/3, the IT8.7/4 is now an established and accepted CMYK test chart for printer profiling. A number of issues relating to formatting, printing, and measuring test charts were described as part of custom printer profiling.

Today printer color management is based largely around reference printing conditions. A number of reference printing conditions were listed including GRACoL, SWOP, FOGRA and CRPC1–CRPC7. It was shown that reference printing conditions can be used to manage color by “printing to the numbers.” Printing to the numbers, using L*a*b* and Δ*E*, provides an easy and sensible metric with which to evaluate a color match. It was shown that if the numbers match, then images will match. Printing to the numbers is a fundamentally important way of working in all aspects of the press and prepress environment, reducing errors, eliminating waste, enabling easy communication between all stakeholders. Printing to the numbers moves printing and proofing away from a visual approach for color matching to an effective numerical process that can be verified by measurement. *The concept of a measurement based, printing to the numbers approach is a key concept in printer color management.*

Of general interest in color management is the effect the smaller print gamut will have on image colors. Four ICC rendering intents were described. Relative and absolute colorimetric intents are often confusing to the end user. It was suggested that the relative colorimetric intent is a great, general purpose intent that can be used in most situations. Absolute colorimetry would be appropriate for the specific purpose of making a side-by-side comparison, for soft proofing and press proofing and also for reproduction of in-gamut logo colors.

Device link profiles for matching color between two pre-identified devices, such as RGB to CMYK or CMYK to CMYK was shown, and ICC device link profiles were described as well as a proprietary type of device link process.

A color management system only works with a stable, repeatable environment. Process control for print devices has become one of the critical areas. The focus of many new process control systems has been instrument based monitoring linked to reporting and analysis software. It is expected that every facility would be using some form of measurement to continuously monitor and track color performance.

The final destination of many color management processes is often the printed image. This chapter provided information relating to the necessary concepts necessary for effective printer color management.

9

Spot Colors & Expanded Gamut Printing

Objectives

- Describe the need for bright and bold colors in package printing.
- Explain the PANTONE MATCHING SYSTEM for spot colors.
- Introduce the concept of simulating spot colors in CMYK.
- Describe the process of expanded gamut printing with CMYK+OGV ink sets.
- Provide tools for the digital press operator to manage spot colors in the DFE.
- Review use of specialized spot color software.

9.1 Introduction

This chapter considers the specification and management of spot colors which are often used in addition to CMYK process color inks. CMYK inks have an inherent small color gamut, and in many areas of printing there is a requirement to print bright and bold colors. On a supermarket shelf, for example, labels and packages are often printed with multiple spot colors to gain a customer's attention.

Spot colors are important for brand identity and are used to create consistency across many branded product items. Spot colors are used in commercial printing adding value and opportunity. Spot color reproduction, however, is often problematic in real-life situations because the concepts surrounding color management of spot colors are often not clearly understood and not properly implemented. Spot color printing can be very successful if we understand the underlying principles, such as color gamut limitations, as described in this chapter.

There a number of ways to specify spot colors. One traditional approach is for a brand owner, such as Wrigley, to use a proprietary shade card system, where the printer is required to visually match a sample by viewing it through a small window, Figure 9.1. This process has many challenges, such as ensuring everybody has a shade card; ensuring that the card doesn't deteriorate; recognising that it is a subjective process, and changing everybody's set of cards if the shade library is changed. Shade cards create difficulties when trying to match color across different printing processes or at diverse locations.

There are other, more open, color matching systems such as PANTONE, FOCOLTONE, or the German RAL system. These systems are also proprietary, however due to

Understanding Color Management, Second Edition. Abhay Sharma.
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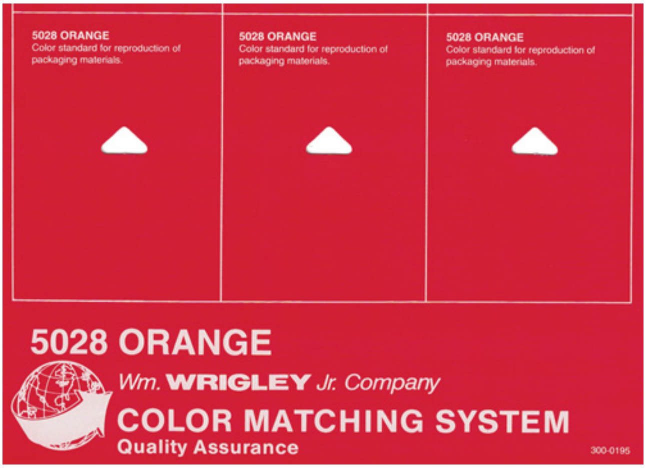

5028 ORANGE
Color standard for reproduction of packaging materials.
5028 ORANGE
Color standard for reproduction of packaging materials.
5028 ORANGE
Color standard for reproduction of packaging materials.
5028 ORANGE
Wm. WRIGLEY Jr. Company
COLOR MATCHING SYSTEM
Quality Assurance
300-0195

Figure 9.1 Printers can use a shade card to ensure their printing matches the customer's requirements, but shade cards have many logistical challenges.

their digital libraries and widespread adoption, they provide greater flexibility compared to a company-specific, shade card system.

In this chapter we show how the PANTONE MATCHING SYSTEM® can be used to specify and reproduce spot colors. The PANTONE system is best known for its fan guides, also called swatch books, Figure 9.2a. An advantage of the PANTONE MATCHING SYSTEM (PMS) is that it can provide true WYSIWYG color – the designer can select a color from a swatch book, Figure 9.2b, and the final printed product should match the selected swatch.

PANTONE colors are specified by a PANTONE number, and are used in many legislative and technical applications. The only block of color allowed on a UK cigarette packet is PANTONE 448, a color called "opaque couché," Figure 9.3a. A spot color in

FORMULA GUIDE
EXTENDED GAMUT
THE PLUS SERIES
PANTONE
THE PLUS SERIES
PANTONE

(a)

(b)

Figure 9.2 (a) PANTONE is a proprietary system that relies on specification of spot colors using swatches printed on coated and uncoated paper. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated. (b) A designer chooses their color palette from a swatch book which ensures "WYSIWYG" color. *Source:* Vukas/Adobe Stock. Reproduced with permission of Adobe Stock.

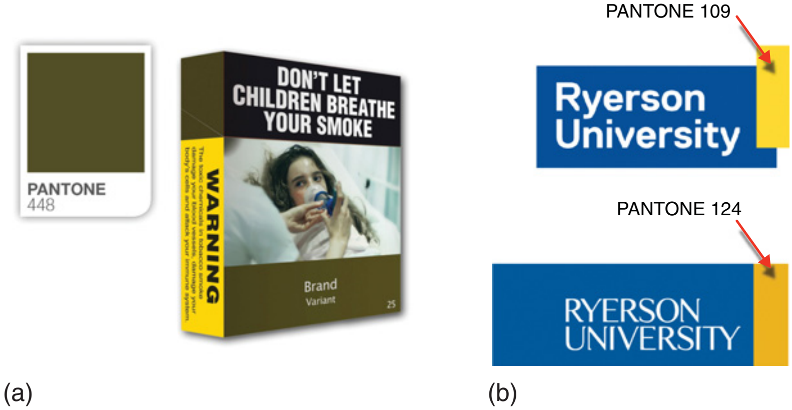


Figure 9.3 (a) UK health legislation seeks to dissuade the consumer by only allowing PANTONE 448 on cigarette packets. (b) Ryerson University recently re-branded and in the new logo, PANTONE 124 was changed to a new, cleaner yellow – PANTONE 109.

this scenario does the exact opposite to what advertisers are usually trying to do – it creates graphics that make the product unappealing to the customer!

The Pantone system is widely used for specification of logo and brand colors. Ryerson University, recently re-branded with a new logo, changing to a new, cleaner yellow – PANTONE 109 from PANTONE 124, Figure 9.3b.

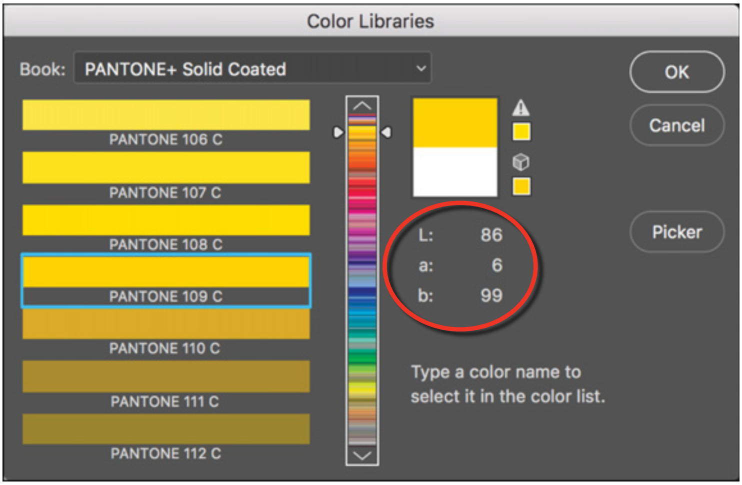
Today spot color inks are primarily used in printing processes, such as flexography and offset lithography, where the customer is willing to pay the extra cost of procuring and printing with a spot color ink, and the run length justifies this investment. There are practical advantages to printing with a spot color ink – it is often easier to maintain color on press when using a single printing ink.

This chapter describes different workflows for managing spot colors via an inkjet RIP or a digital press DFE. Most inkjet devices and digital presses do not have the ability to use a spot color ink or toner, and must simulate spot colors using CMYK. In this chapter we consider simulating the process of finding a CMYK mix that will create the color of a spot color.

PANTONE libraries are specified in terms of L*a*b*, and this immediately provides a connection to an ICC workflow. Applications such as Photoshop can translate, for example Ryerson University yellow, PANTONE 109 C to an L*a*b* of 86, 6, 99, Figure 9.4. Once we have an L*a*b* value for a spot color it can be processed via ICC profiles and conventional color-management. This is the process that underlies most inkjet RIPs and digital press DFEs.

This chapter introduces an important new area in color reproduction called expanded gamut printing. Expanded gamut printing widens the range of reproducible colors by adding one or more inks (e.g. Orange, Green, Violet) to CMYK process inks. Expanded gamut printing can therefore create more colorful graphics. An expanded gamut print process can create many spot colors via simulation in CMYKOGV.

An important benefit of an expanded gamut system is that a press can use a fixed seven-color palette and run a number of different jobs with different spot colors without any press wash ups. Expanded gamut printing is therefore also called “fixed palette


Color Libraries

Book: PANTONE+ Solid Coated

PANTONE 106 C
PANTONE 107 C
PANTONE 108 C
PANTONE 109 C
PANTONE 110 C
PANTONE 111 C
PANTONE 112 C

L: 86
a: 6
b: 99

Type a color name to select it in the color list.

Figure 9.4 Ryerson University yellow is PANTONE 109 C, which has an L*a*b* of 86, 6, 99, displayed via Photoshop's Color Libraries.

printing" because a printer can simply maintain seven printing stations and print different spot color jobs without changing inks. In this chapter expanded gamut, extended gamut, and fixed palette printing are all taken to mean the same thing and these terms are used synonymously.

There are a number of print-related benefits of expanded gamut printing, such as the reduction in number of press wash ups, ability to gang jobs, better process control on press, reduced ink usage, etc. Expanded gamut printing is readily available in all aspects of prepress, printing, and proofing; from swatch books to workflow software to digital presses and inkjet proofers.

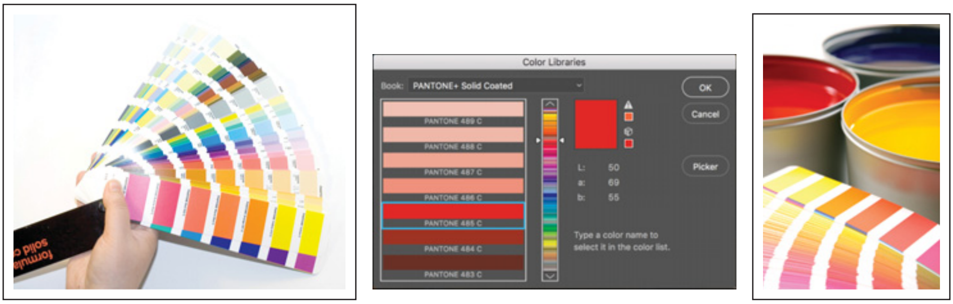
There are competing pressures on printing today – to improve (increase) color gamut and at the same time reduce costs and reduce time in the plant. Using an expanded gamut ink set meets these requirements. We are likely to see increased use of expanded gamut tools in all aspects of printing. Expanded gamut printing was visible in many areas at the printing industry's largest trade show, drupa in Düsseldorf, 2016. Support for expanded gamut printing should be part of every vendor's product road map and printers must also consider rapid adoption of this efficient color technology.

9.2 Specifying a Spot Color – PANTONE MATCHING SYSTEM®

The PANTONE MATCHING SYSTEM® (PMS) consists of three components – fan books called Guides, Digital Color Libraries in software, and an ink formulation system, Figure 9.5.

9.2.1 PANTONE Guides

The guides are swatch books, where each page or leaf contains varying shades of a color, Figure 9.6. The guides can be spread out in a fan-like manner. There are a number


formula solid c
Color Libraries
Book: PANTONE+ Solid Coated
PANTONE 489 C
PANTONE 488 C
PANTONE 487 C
PANTONE 486 C
PANTONE 485 C
PANTONE 484 C
PANTONE 483 C
OK
Cancel
Picker
L: 50
a: 69
b: 55
Type a color name to select it in the color list.

(a) (b) (c)

Figure 9.5 The PANTONE MATCHING SYSTEM® consists of (a) swatch books for different paper types, (b) digital Color Libraries in software, and (c) an ink formulation recipe.

of different guides for metallics, pastels, neons, skin tones, etc. The guides have evolved and changed, and there are many different naming conventions. In this section we describe three guides from the PLUS series – FORMULA GUIDE, COLOR BRIDGE Guide, and EXTENDED GAMUT Guide.

The guides are printed on different paper substrates, indicated by a capital letter: C = coated paper, U = uncoated paper, M = matte paper, and XGC = extended gamut, coated paper. The different substrates help the user evaluate the effect that the paper has on a printed color.

The FORMULA GUIDE is the basic fan book that shows a color swatch and the PANTONE number for that swatch. A color is specified according to a number, such as PANTONE 182 C, a pink color, Figure 9.6. The FORMULA GUIDE contains around 1700 swatches that cover a full range of colors. Importantly, each patch in the

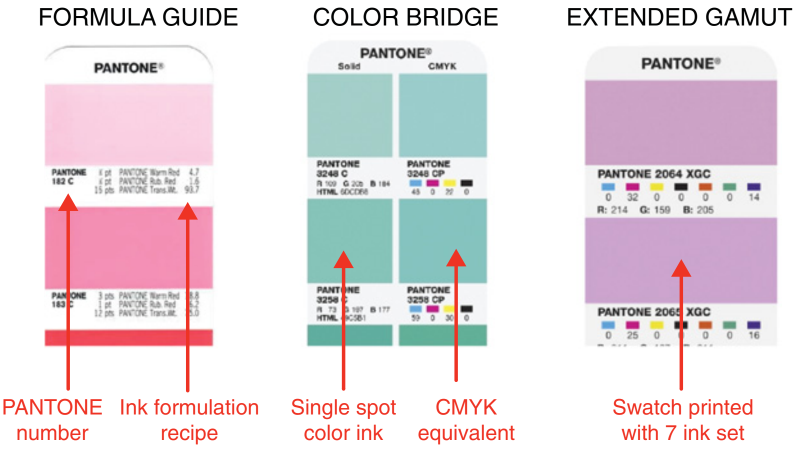

FORMULA GUIDE
COLOR BRIDGE
EXTENDED GAMUT
PANTONE®
PANTONE 182 C
PANTONE 183 C
PANTONE®
Solid
CMYK
PANTONE 3248 C
PANTONE 3248 CP
PANTONE 3258 C
PANTONE 3258 CP
PANTONE®
PANTONE 2064 XGC
R: 214 G: 159 B: 205
PANTONE 2065 XGC
PANTONE number
Ink formulation recipe
Single spot color ink
CMYK equivalent
Swatch printed with 7 ink set

Figure 9.6 The FORMULA GUIDE is the basic swatch book that describes each spot color. The COLOR BRIDGE shows each spot color and its equivalent in CMYK. The new EXTENDED GAMUT Guide shows each spot color reproduced in seven inks – CMYKOGV. *Source:* X-Rite. Reproduced with permission of X-Rite, Incorporated.

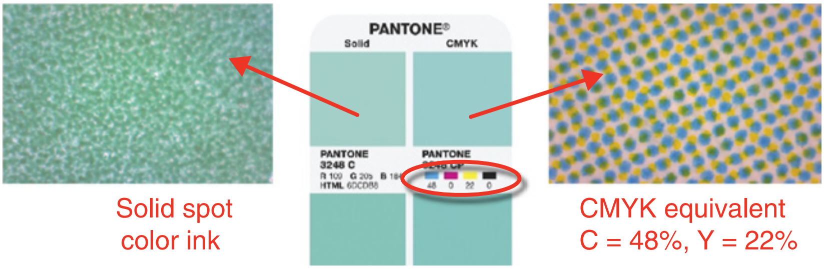


Figure 9.7 Microscopy reveals that the left column in the COLOR BRIDGE is printed with a single green ink, while the right column is printed using a CMYK "build" or "mix." The CMYK equivalent consists of cyan and yellow to match the green spot color ink.

FORMULA GUIDE is made from a single color ink, printed using an offset printing process.

In the bottom part of each of the FORMULA GUIDE swatches is a "formula" or ink recipe that can be used to mix inks that will create that swatch color. In the recipe there will typically be some base colors to which transparent white or black ink is added. In Figure 9.6, we see that FORMULA GUIDE PANTONE 182 C can be made from a recipe that uses small amounts of Warm Red and Rubine Red base inks, to which Transparent White is added.

The COLOR BRIDGE is a swatch book that shows which PANTONE colors can be accurately simulated by a four-color print process, Figure 9.7.

The COLOR BRIDGE guide is split into two columns and shows a spot color on the left printed with a single ink – PANTONE 3248 C, and on the right is a simulation of that color, printed using a four-color CMYK process, Figure 9.7. Microscopy clearly shows that the left hand column of the COLOR BRIDGE is printed with a single green spot color ink, while the right hand column is created with a CMYK mix. Note that the CMYK mix for PANTONE 3248 C is cyan = 48% and yellow = 22%, and in the micrograph there are therefore halftone dots of cyan and yellow ink only. The magnified image also confirms that the cyan halftone dots are around double the size of the yellow dots, as required by the ink recipe.

The COLOR BRIDGE is used to determine if it is possible to reproduce a spot color by a CMYK mix. If a color looks the same in both the left and right columns of the COLOR BRIDGE, then, in terms of color, it doesn't matter how the job is printed – it can be printed using a single PANTONE spot color ink or the same color can be created more economically using a CMYK print process. If a color is out of gamut of the CMYK print process, then the right column will not match the chosen spot color, and we can say that there is no CMYK mix that can accurately create the requested spot color.

The CMYK values indicated in the COLOR BRIDGE, Figure 9.7, are unlikely, and in most cases *will not, create the required swatch color with any accuracy* on your device. The CMYK values are only provided as a guide, and can be used as a starting point.

On the other hand, the RGB values in the COLOR BRIDGE are sensible to use in a display system, because their color is fully specified as the RGB values are associated with the sRGB color space.

The COLOR BRIDGE concept extends to another guide, the EXTENDED GAMUT Guide, Figure 9.6. The EXTENDED GAMUT Guide is a fan book with 1729 swatch colors. This is the newest guide, released in late 2015, and is printed using seven inks – CMYK + orange, green and violet. The guide was printed at a North American package printer on an offset lithographic printing press, on coated paper containing optical brightening agents. In this guide, a swatch color is described as, for example, “PANTONE 2064 XGC.”

The basic premise of the EXTENDED GAMUT Guide is that, by adding three additional inks (orange, green and violet) to the traditional CMYK ink set, it is possible to accurately simulate many more FORMULA GUIDE colors than could be simulated by CMYK alone. Brand owners, designers, printers and end-users can use the guide to make an informed decision on how a spot color will reproduce if sent to a seven-color, extended gamut print process.

It is expected that, compared to reproduction of a spot color in the COLOR BRIDGE (that uses CMYK), many more of the FORMULA GUIDE colors can be matched by the EXTENDED GAMUT Guide. It may be non-intuitive but the EXTENDED GAMUT Guide does not seek to extend the gamut of the spot color set, rather it seeks to show the reproduction of existing spot colors in a printing process with more inks.

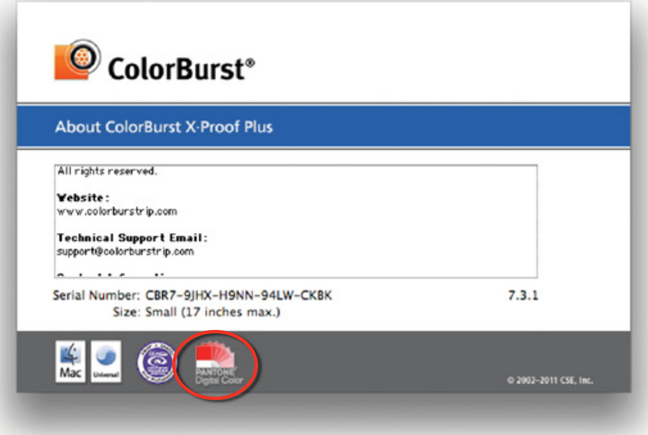
It is relevant to note that there is never the need to use all seven colors at any one time – in fact each color in the EXTENDED GAMUT Guide has been created with a maximum of three ink combinations at any one time. As with the CMYK COLOR BRIDGE, the actual CMYKOGV tint values in the EXPANDED GAMUT Guide are probably not applicable to your printing system.

Consider how to use the EXTENDED GAMUT Guide. First, the user identifies the required PMS solid spot color from the left column of the COLOR BRIDGE. Next the user is able to see the reproduction of this color in CMYK from the right column of the COLOR BRIDGE. If the user is happy with the color shown then the spot color can be printed using a CMYK process. For more colorful swatches the COLOR BRIDGE may not show a good color match in CMYK, so the user can turn to the EXTENDED GAMUT guide. *Using the same page number*, the user can assess the required swatch and see what it will look like if printed in CMYK and also in CMYKOGV. On finding an agreeable match the user would indicate their choice of, for example, “PANTONE 2070 XGC” in their files, which indicates an extended gamut printing process is required to realize the required swatch color.

9.2.2 Pantone Digital Color Libraries

An important part of the PANTONE MATCHING SYSTEM is Pantone’s Digital Color Libraries. The Digital Color Libraries are a critical (but hidden) part of the PMS system. Color prepress software can license, and use internally, the Pantone Digital Color Libraries usually indicated by an icon on the splash screen, see for example ColorBurst, Figure 9.8. Adobe Photoshop and the other Adobe applications have licensed the Pantone Digital Color Libraries so that a designer can use a menu to select a PANTONE color for their artwork. Illustrator and Photoshop’s Color Library dialogs are shown in Figure 9.9.

During design and file construction there is the ability to create an element as a PANTONE-labelled spot color, as a separate channel in an image. In the Photoshop example, Figure 9.10a, we see that most of the graphics are encoded as CMYK, but there is a spot color channel for PANTONE 2945 C and 109 C. In spot color workflows it is


ColorBurst®
About ColorBurst X-Proof Plus
Mac
PANTONE Digital Color

All rights reserved.

Website:
www.colorburstrip.com

Technical Support Email:
support@colorburstrip.com

Serial Number: CBR7-9JHX-H9NN-94LW-CKBK 7.3.1
Size: Small (17 inches max.)

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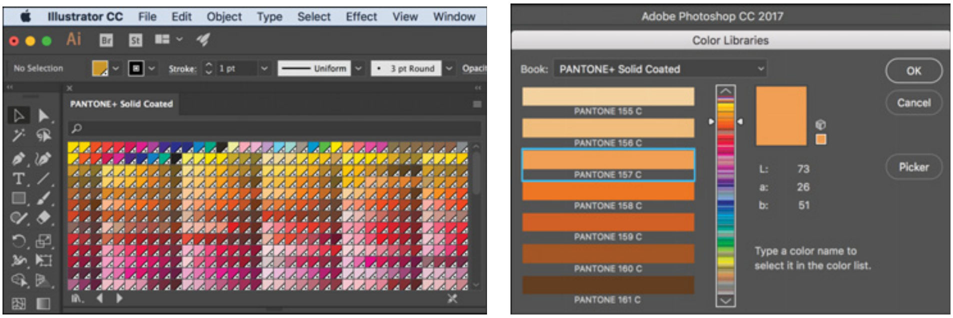
Figure 9.8 Software such as the ColorBurst proofing RIP, license the PANTONE Digital Color Libraries and indicate this via an icon on their splash screen.

important to use file formats that support spot color channels. It is necessary to use a TIFF or other professional file format as consumer file formats may not support spot color channels.

In a pdf workflow, the spot color channel is retained in the pdf file. When we send this file to an output system, the RIP or DFE examines all the elements in a file and identifies and processes any PANTONE named color elements, according to pre-determined color processing rules and workflow options.

It is important that the spot color channel is not renamed or changed from the official PANTONE name. As long as the user does not edit or change the name and everyone follows PANTONE's proprietary naming convention, images containing PANTONE named spot color channels will be recognized and processed through the workflow, and handled from design to prepress to output.


Illustrator CC
File
Edit
Object
Type
Select
Effect
View
Window
No Selection
Stroke:
1 pt
Uniform
3 pt Round
PANTONE+ Solid Coated
Adobe Photoshop CC 2017
Color Libraries
OK
Cancel
Picker
PANTONE 155 C
PANTONE 156 C
PANTONE 157 C
PANTONE 158 C
PANTONE 159 C
PANTONE 160 C
PANTONE 161 C

Book: PANTONE+ Solid Coated

L: 73
a: 26
b: 51

Type a color name to select it in the color list.

(a) (b)

Figure 9.9 Adobe Illustrator and Photoshop's Color Library dialogs, allow the designer to select and use a PANTONE-named color.

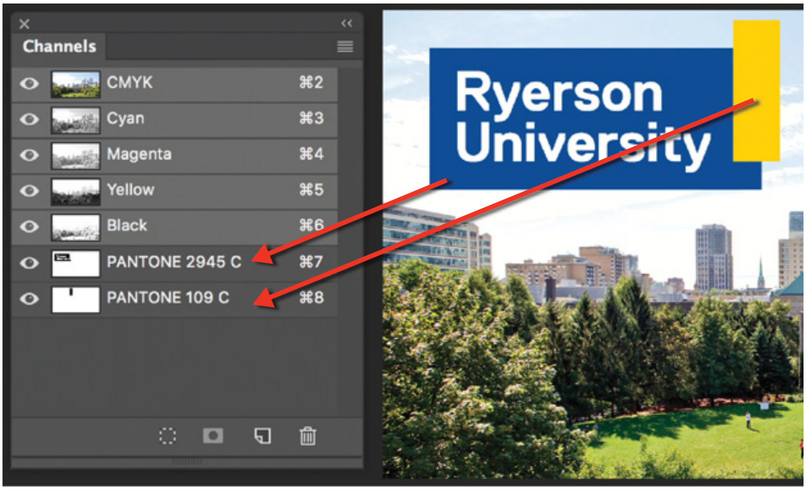
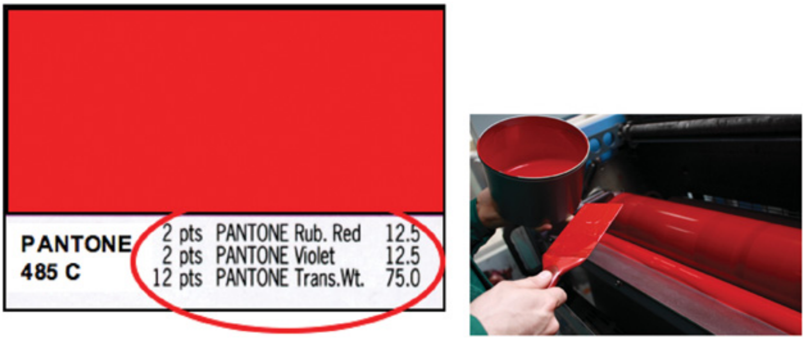

Channels
CMYK ⌘2
Cyan ⌘3
Magenta ⌘4
Yellow ⌘5
Black ⌘6
PANTONE 2945 C ⌘7
PANTONE 109 C ⌘8
Ryerson University

Figure 9.10 Photoshop's Channel palette shows that this image contains CMYK information and two spot color channels for the Ryerson University logo. The spot channel names must not be edited in order that they be recognized by other applications in a workflow.

9.2.3 PANTONE Ink Formulation Recipes

The final part of the PMS system is ink formulation. PANTONE provides, via the FORMULA GUIDE, a recipe to formulate ink that will create a selected swatch color on press, Figure 9.11.

To make a PANTONE ink for an offset press, the ink supplier is contacted. The supplier uses the recipe from the FORMULA GUIDE to make the required ink using appropriate amounts of the 14 base colors and white and black ink. The recipe for Pantone 485, for example, requires 2 parts Rubine Red, 2 parts Violet and 12 parts Transparent White. These proprietary PANTONE Basic Colors, in this ratio, create a printing ink that when used will create the color shown by the PANTONE 485 C swatch.


PANTONE
485 C
2 pts PANTONE Rub. Red 12.5
2 pts PANTONE Violet 12.5
12 pts PANTONE Trans.Wt. 75.0

(a) (b)

Figure 9.11 The PANTONE MATCHING SYSTEM provides (a) an ink recipe that allows mixing of an ink from base pigments for (b) an offset press.

9.2.4 Advantages and Disadvantages of the PMS System

There are advantages and disadvantages to the PANTONE MATCHING SYSTEM.

The PMS system is carefully controlled and regulated by X-Rite/PANTONE. It is a proprietary system that requires all parties – the designer, prepress department and printer – to buy-in to the system. As the PMS system offers swatch guides, digital libraries and an ink formulation system it addresses every part of the color reproduction process from design to prepress to printing. When all parties are on board and a PMS system is implemented and used correctly, spot colors can be efficiently and accurately managed throughout the print chain.

An advantage of the PMS system is that it can provide true WYSIWYG color – the designer can select a color from a physical swatch book and the final printed product will match closely the selected swatch color. The availability of a physical swatch book helps in color communication and the physicality of the swatch book reassures many users.

The PMS system is easy to use, and PMS colors are referred to by a simple naming convention, e.g. PANTONE 485 C (the PMS system requires no knowledge or understanding of the L*a*b* color system). The PMS system is established and widely accepted in the design and prepress communities and is readily available in all mainstream design and prepress software.

Using a PANTONE ink is advantageous in terms of color gamut as the color will always be “in gamut” as the ink has been specially created for that color. There are advantages in terms of quality control. When using a PANTONE ink we can better control the printing process as a PANTONE ink is only one ink, and the press operator need only carefully monitor the ink density for a single printing unit. If a color is made up of two to three process inks we need to make sure the color is correct as they mix together during printing. Also there is the opportunity for drift on press, especially for long press runs where it may be difficult to continuously monitor many different printing units.

When managing color using ICC profiles it is necessary to print and measure a test chart. A big advantage to the PMS system is that there is no requirement to print and measure test charts. The FORMULA GUIDE is a real press sample and removes the need for the user to calibrate and characterize the printing process – it has already been done by Pantone!

The PMS system can exist in images and graphics in parallel with ICC workflows. The PANTONE colors are specified in terms of L*a*b*, which means that their reproduction can be easily integrated with ICC color management.

A disadvantage of the PMS system is that only specific shades are available. A designer must choose from provided swatches and there is little ability to select a color that is in-between two swatches or otherwise deviate from the fixed palette of colors.

To manage colors using the PMS system there is a requirement for all participants to buy into the system, thus the designer must purchase a FORMULA GUIDE, and the printer too should have a FORMULA GUIDE at press side. It is necessary to replace a FORMULA GUIDE on a regular basis. The designer should update their swatch book as the books can fade in the sunlight in a bright office, and at press side a swatch book can become soiled through use. It is necessary to ensure that all parties are using the same version of the book, and to have coated or uncoated guides depending on the paper being used to print the job.

A consideration in dealing with the PANTONE Digital Color Libraries is that the version of the libraries is continuously changing and as they are internal libraries it is difficult to ascertain their version number. There can be a discrepancy between the Digital Color Libraries in different versions of Adobe software and also a discrepancy between the Digital Color Libraries and a FORMULA GUIDE. With the release of the PANTONE PLUS system the situation is greatly improved, nevertheless users should be aware of the potential for differences, especially when using legacy software.

There are disadvantages to using a PANTONE ink. In a printing plant, it is important to correctly estimate the amount of ink needed, and there may be a delay while the printer waits for the ink to be formulated and shipped. Of course if, at the last moment, the customer asks for an increase in the print run this request cannot be easily accommodated. Left over spot color ink is also an issue, and many press rooms have a collection of cans with different spot color inks that are waiting for the next customer job that may coincidentally request the same color. There is often discussion on the pooled reuse of spot color inks.

A disadvantage of the PANTONE system is that many printing systems, such as inkjet devices and digital presses, do not have the ability to introduce a spot color ink or toner. PMS colors can still be matched on an inkjet device or a digital press, but we need to simulate that color using available colorants.

At the end of the day a separate spot color workflow and printing plate is expensive and time consuming, but the job may warrant it and the customer may be prepared to pay for it.

9.3 Printing a Spot Color

If a digital file contains a spot color element, there are different ways to create the requested color. Depending on the available workflow and equipment options a spot color can be:

- retained as is and printed using a single spot color ink
- converted to CMYK and printed using process colors.

We note that many customers will insist on the same level of accuracy, irrespective of whether the job has been printed with a single spot color ink, or CMYK process inks.

9.3.1 Printing with a Spot Color Ink

In this section we consider printing where the spot color is retained as is, and is printed using a single spot color ink. Printing with a spot color ink represents the traditional approach to printing spot colors and is a process that can be used today in offset, flexographic and gravure printing. Digital presses and inkjet systems cannot in general print with a spot color toner or ink, so the process described here is not available in these systems.

Let us consider the example of a university poster, and see how this could be printed, Figure 9.12. The poster consists of an image of a campus scene and the Ryerson University logo. In this example, the campus scene is a 4-color CMYK image, and the university logo at the top of the poster is designed using PANTONE 2945 C and 109 C.

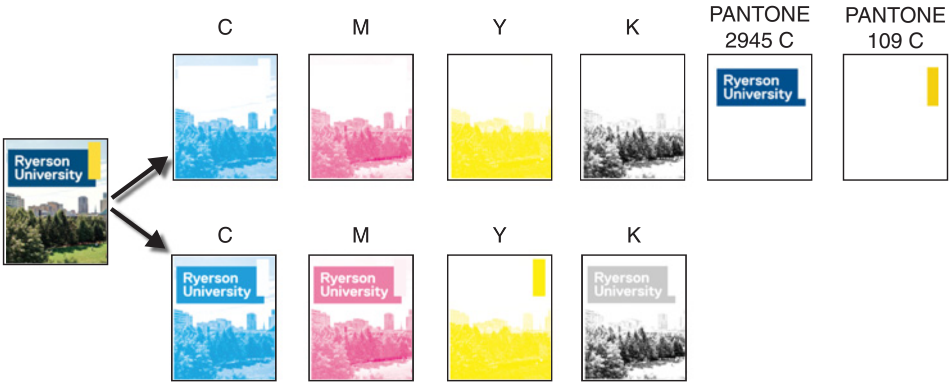


Figure 9.12 A graphic can be printed in CMYK + two spot colors (top row). Another way to print this job is to merge the spot channels into CMYK (lower row). An offset press can use either method, while a digital/inkjet press must always merge a spot color into CMYK.

We see that the prepress separations contain information for the campus scene in the cyan, magenta, yellow, and black channels. To print this job on an offset press, Figure 9.12 (top row), we can make cyan, magenta, yellow, and black printing plates, and we would use cyan, magenta, yellow, and black inks in four printing units.

To print the university logo we create separate spot channel plates for the PANTONE colors. It is necessary to order PANTONE 2945 C and 109 C ink from an ink supplier, we need to order this ink and have it delivered and then we can print the job.

A large printing facility may have their own "ink kitchen" where spot color inks are formulated on-site. Another approach is to use an external facility that can formulate and supply inks in the amount required for each press job. Some ink providers will be a Pantone approved "Licensed Printing Ink Manufacturer."

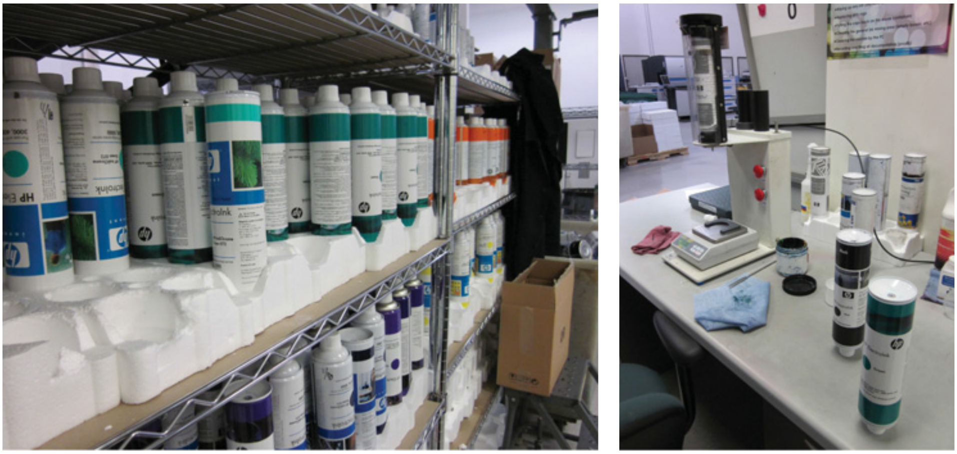
Digital presses, such as the HP Indigo series, can also use a Pantone-formulated spot color, and using appropriate amounts of base colorants a canister of electroink for a specific PANTONE color can be formulated, Figure 9.13. The Rochester Institute of Technology (RIT) in Rochester, NY, offers an HP Indigo ink mixing service for HP presses in North America.

On an offset (or HP Indigo press), we put C, M, Y, and K inks in four printing units and then PANTONE 2945 C and 109 C ink goes into the fifth and sixth printing units. So we print the job as CMYK+2, i.e. four process colors for the campus image and two separate printing plates for the university logo.

9.3.2 Simulating a Spot Color in CMYK

There is another way to print the same university poster. The whole page – the campus scene *and* the spot colors – can be printed with a CMYK print process, lower part of Figure 9.12. Printing a spot color in CMYK is an economical procedure and can be used by all printing systems – offset, flexography, gravure and also digital presses and inkjet devices.

The campus scene is of course already in CMYK format, and we see it has components in each of the CMYK separations. But we can also compute how much CMYK



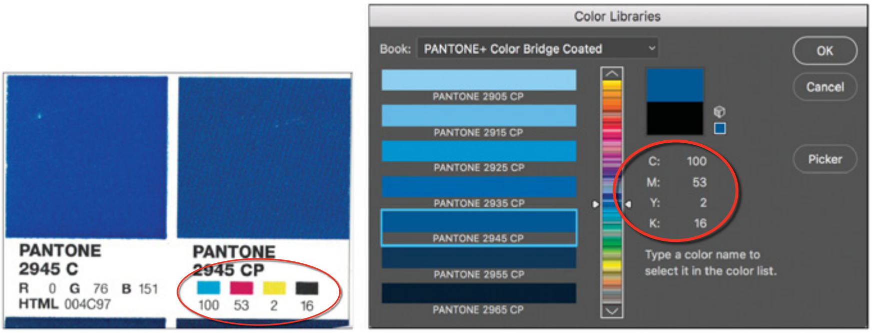
(a) (b)

Figure 9.13 (a) Base colors are used to (b) formulate spot color electroink for HP Indigo digital presses at Rochester Institute of Technology, NY.

ink we need to make the university logo. There will be some combination of CMYK inks that can simulate PANTONE 2945 C and 109 C. So we see that the complete job (CMYK + two spot colors) can all be printed using CMYK, and we see how all the colors are represented within the CMYK separations, lower part of Figure 9.12.

The conversion of 2945 C (and 109 C) into CMYK is specified either from the COLOR BRIDGE Guide, or from the Digital Color Library in Photoshop, Figure 9.14. Both tools provide the conversion of 2945 C into CMYK of 100, 53, 2, 16. These CMYK values are unlikely to be accurate and in practice a RIP or other prepress workflow software can better calculate how much CMYK is needed for the spot color equivalency.

The procedure just described is an established process for the reproduction of spot colors in CMYK printing. *We can say that we are using the four process colors to simulate PANTONE 2945 C and 109 C.*



PANTONE
2945 C
R 0 G 76 B 151
HTML 004C97

PANTONE
2945 CP
100 53 2 16

Color Libraries

Book: PANTONE+ Color Bridge Coated

PANTONE 2905 CP
PANTONE 2915 CP
PANTONE 2925 CP
PANTONE 2935 CP
PANTONE 2945 CP
PANTONE 2955 CP
PANTONE 2965 CP

C: 100
M: 53
Y: 2
K: 16

Type a color name to select it in the color list.

(a) (b)

Figure 9.14 Today, the PANTONE COLOR BRIDGE guide and the Color Library in Adobe Photoshop agree, but this was not always the case.

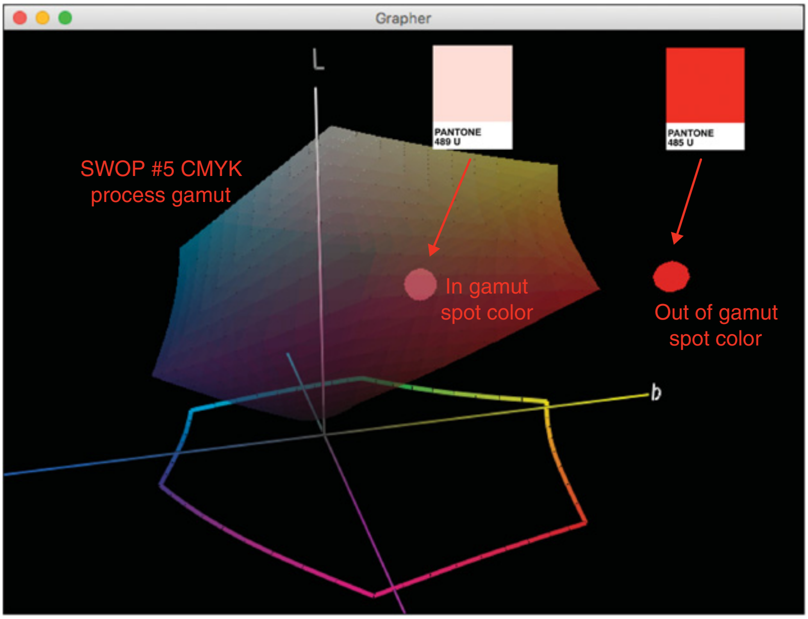


Figure 9.15 In this L*a*b* diagram, PANTONE 489 U is in gamut of the chosen print process and therefore can be reproduced by a CMYK "build." PANTONE 485 U is out of gamut and there is no CMYK combination that can accurately create this spot color.

When converting a spot color to CMYK there is always the need to consider the capability of the destination print process, in particular its color gamut. Consider the example of an in-gamut and an out-of-gamut spot color. In Figure 9.15 we see that PANTONE 489 U is in gamut of the SWOP #5 print process, in other words there is some combination of CMYK that can accurately represent the color of the PANTONE 489 U swatch, as shown in this L*a*b* diagram. For PANTONE 489 U we have the choice of retaining the color as a spot color, or merging it into CMYK.

PANTONE 485 U is more colorful and via analysis of the L*a*b* diagram, we see that it is out of gamut of the chosen print process. In other words there is no CMYK combination on a press operating to SWOP specifications that can create the PANTONE 485 U color swatch. We may say that PANTONE 485 U is out of gamut of this print process, and the only way to accurately reproduce this color is via a spot color ink.

It is interesting to note that the COLOR BRIDGE offers CMYK equivalent values for both PANTONE 489 U (0, 20, 20, 0) and PANTONE 485 U (0, 73, 92, 1).

9.4 Spot Colors and Digital Presses

Spot color printing is a very important business consideration in digital printing as it adds value and opportunity.

As most digital presses do not offer a spot color toner the printing of spot colors on digital presses is usually done via CMYK simulation. It is challenging to find the correct

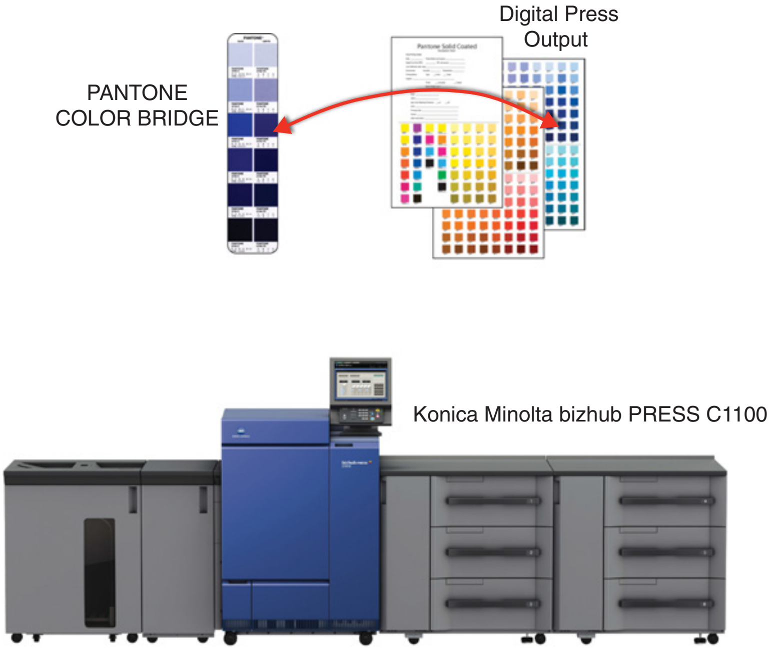


Figure 9.16 In digital presses, controller software has a pdf file that contains the complete PANTONE library. Printing this on your digital press creates a custom COLOR BRIDGE for your press and paper. Image of digital press *Source:* Konika Minolta. Reproduced with permission of Konica Minolta.

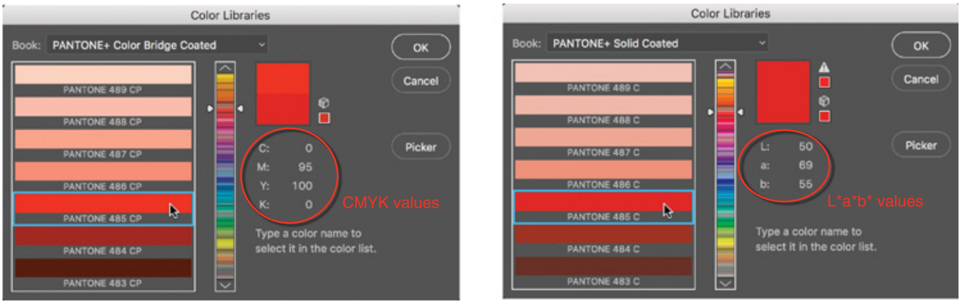
CMYK values for a digital press and there is the ever-present issue of the finite gamut of the print process.

9.4.1 Creating a Swatch Book on a Digital Press

A useful approach in spot color management on a digital press is to create a "customized COLOR BRIDGE," Figure 9.16. The whole PANTONE library is provided within the DFE/controller as a pdf file that can be printed on a digital press using the presses' paper and calibration settings. When this file is printed on a digital press, this effectively creates the right hand side of the COLOR BRIDGE. Printing the supplied spot color pdf file creates a CMYK simulation and visual representation of each of the PANTONE spot colors for your digital press and the condition it is in. Importantly, if the user selects colors directly from this printed file, they will achieve the color they see, as by definition all the swatches on the printed sheet are achievable by the print system. One way to use the "customized COLOR BRIDGE" is to say to the customer, "here is the swatch color rendered on our digital press", is this acceptable?

9.4.2 Spot Color Matching in Digital Presses

A spot color can have a CMYK or L*a*b* value associated with it, which creates two possible workflows in a digital press, Figure 9.17. In the first workflow, the PANTONE


Color Libraries
PANTONE 489 CP
PANTONE 488 CP
PANTONE 487 CP
PANTONE 486 CP
PANTONE 485 CP
PANTONE 484 CP
PANTONE 483 CP
OK
Cancel
Picker
Color Libraries
PANTONE 489 C
PANTONE 488 C
PANTONE 487 C
PANTONE 486 C
PANTONE 485 C
PANTONE 484 C
PANTONE 483 C
OK
Cancel
Picker

Book: PANTONE+ Color Bridge Coated

C: 0
M: 95
Y: 100
K: 0

CMYK values

Type a color name to select it in the color list.

Book: PANTONE+ Solid Coated

L: 50
a: 69
b: 55

L*a*b* values

Type a color name to select it in the color list.

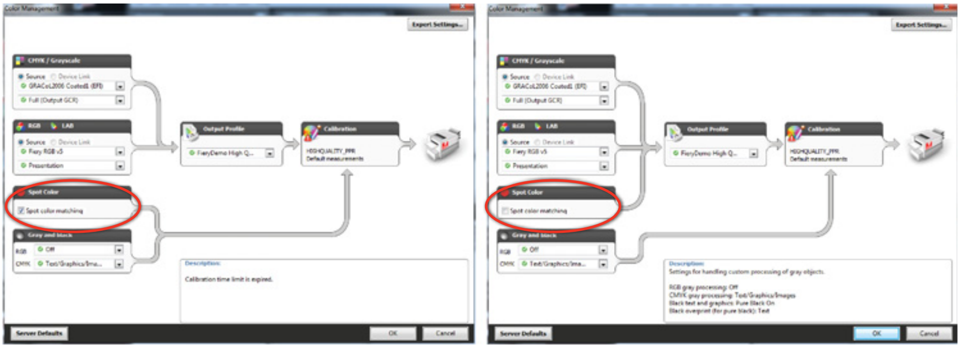
Figure 9.17 Each PANTONE swatch has an associated CMYK value and an L*a*b* value, either of these can be used, so there are often two different workflows in a digital press.

digital library is used to convert spot colors into CMYK for printing. The second way is to convert spot colors into L*a*b* and then use an ICC output profile to render the spot color on a digital press. The processing option can be chosen via a command called different things in different controllers, e.g. enabling or disabling "Spot color matching," Figure 9.18.

Consider printing a spot color with its CMYK value. In a digital press controller, a spot color can be converted into CMYK using the library value and these instructions can be sent to the printing engine, using the paper calibration, see for example the Fiery Command WorkStation workflow, Figure 9.18a.

There are significant problems with this process. We have already described how the CMYK values are unlikely to be appropriate for your chosen printing process. This spot color workflow is unlikely to work with any level of accuracy or certainty. An option in many DFEs is to have a press-specific lookup table with CMYK recipes that are closer to your digital press.

The other way to process a spot color in a DFE is to use the L*a*b* value for the spot color and an ICC output profile. In this route, a spot color in the file is identified by its PANTONE spot color name and is replaced by its L*a*b* value. An ICC output profile is used to take an L*a*b* value and determine the appropriate amounts of CMYK that when sent to that device, will create that color.


Color Management
Export Settings...
CMYK / Grayscale
RGB
LAB
Output Profile
Calibration
Spot Color
Gray and black
Description:
Server Defaults
OK
Cancel
Color Management
Export Settings...
CMYK / Grayscale
RGB
LAB
Output Profile
Calibration
Spot Color
Gray and black
Description:
Server Defaults
OK
Cancel

● Source ○ Device Link
GRACoL2006 Coated1 (EFI)
Full (Output GCR)
● Source ○ Device Link
Fiery RGB v5
Presentation
FieryDemo High Q...
HIGHQUALITY_PPR
Default measurements
☑ Spot color matching
RGB Off
CMYK Text/Graphics/Ima...

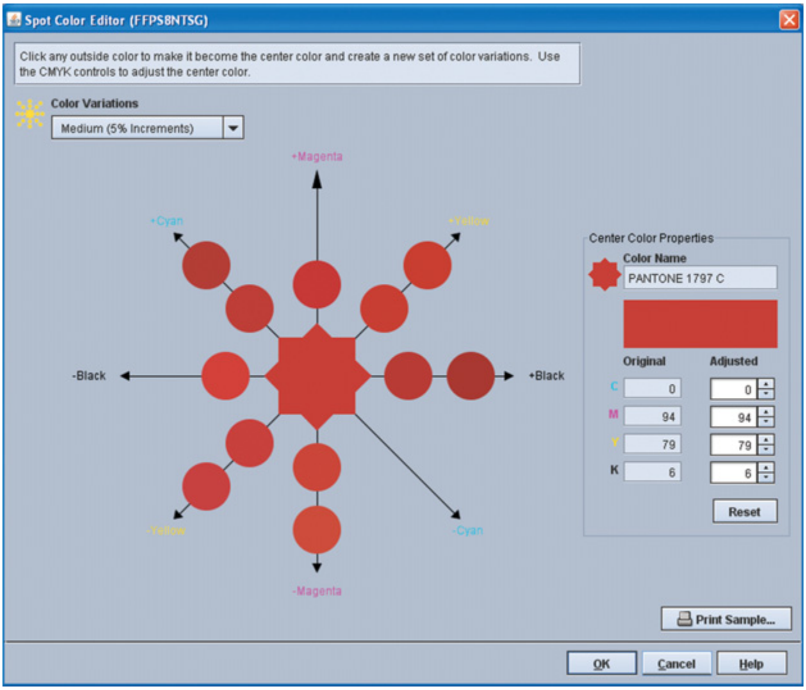
Calibration time limit is expired.

● Source ○ Device Link
GRACoL2006 Coated1 (EFI)
Full (Output GCR)
● Source ○ Device Link
Fiery RGB v5
Presentation
FieryDemo High Q...
HIGHQUALITY_PPR
Default measurements
☐ Spot color matching
RGB Off
CMYK Text/Graphics/Ima...

Settings for handling custom processing of gray objects.

RGB gray processing: Off
CMYK gray processing: Text/Graphics/Images
Black text and graphics: Pure Black On
Black overprint (for pure black): Text

Figure 9.18 In the efi Fiery Command WorkStation – "Spot color matching" uses the CMYK value for a spot color, while no "Spot color matching" uses an ICC output profile to manage colors.



Spot Color Editor (FFPS8NTSG)

Click any outside color to make it become the center color and create a new set of color variations. Use the CMYK controls to adjust the center color.

Color Variations: Medium (5% Increments)

Center Color Properties

Color Name: PANTONE 1797 C

	Original	Adjusted
C	0	0
M	94	94
Y	79	79
K	6	6

Figure 9.19 The CMYK build for a spot color can be adjusted based on user preferences, or the recipe can be visually iterated using a digital press spot color editor.

9.4.3 Spot Color Editor for a Digital Press

A digital press DFE will usually provide an editor that allows the user to modify the default CMYK values for a spot color based on personal choice and visual evaluation, Figure 9.19. Most DFEs allow the user to alter the original CMYK values and then to use the adjusted CMYK values in their spot color workflow.

There are several reasons you may want to adjust the default values in the spot colors libraries in your controller. The starting CMYK values may not be appropriate for the press. The spot color may be out of gamut, so the user can use a spot color editor to find a different replacement color that they think is least objectionable, or, the customer may have a preference and personal choice about color.

There are a number of DFE spot color systems that allow you to visually or via measurement, tune and iterate until you are closer to the desired outcome. Once this new value has been established it can be put back in the library and used for all subsequent jobs, or it can be renamed and used for particular customers or particular types of jobs.

9.5 Expanded Gamut Printing

An important new area in color reproduction is called *expanded gamut printing*, where the color gamut of a CMYK print process is expanded by adding, for example, Orange, Green, and Violet to create a CMYKOGV ink set. In this context, “expanded gamut,”

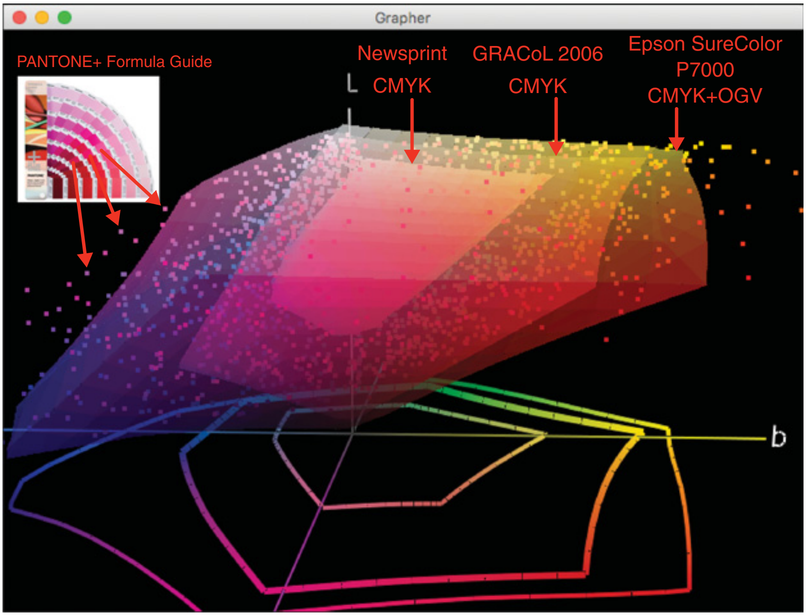


Figure 9.20 The Pantone Formula Guide contains a number of spot colors shown in this L*a*b* diagram as small dots. The number of in-gamut spot colors is dependent on the size of the print gamut, the larger print gamuts will encompass more spot colors.

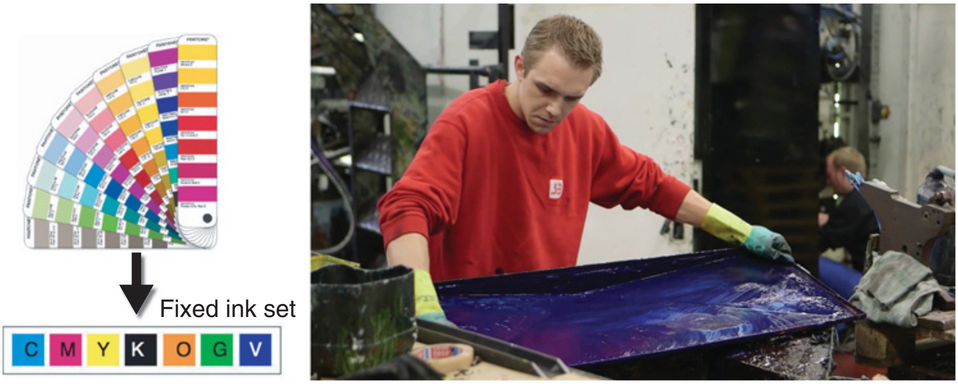
"extended gamut" and "fixed palette printing," are all taken to mean the same thing and these terms are used synonymously. And while the examples may refer to CMYKOGV, the seven-colors can be different, and may be CMYK+OGB (orange, green, blue) or CMYK+RGB (red, green, blue), or variations thereof.

Printing for many years has used cyan, magenta, yellow, and black ink. Due to imperfections, such as unwanted absorptions by ink pigments, CMYK processes are not able to reproduce all the colors in a color space, resulting in a much smaller color gamut then ideal. Expanded gamut printing expands the range of reproducible colors by adding one or more inks, so that we may print with a colorant set of, for example, CMYKOGV.

The effect of using additional colorants, in any printing system (flexo, offset, inkjet, xerography, etc.) is to expand the CMYK gamut, as shown in an L*a*b* diagram, Figure 9.20. In this figure, CMYK gamuts are represented by Newsprint and GRACoL 2006, while an Epson SureColor P7000 inkjet printer with CMYKOGV inks creates an expanded gamut.

The larger gamut extent allows for the reproduction of colors that are out of gamut of a CMYK-only print process. If images are processed to take advantage of the destination print gamut they will look more colorful than if printed using only CMYK inks. The results of using CMYKOGV, in any print process, will be evident in bright, vivid colors, depending on image content.

Another advantage of an expanded gamut print process is that it can simulate many more spot colors. Figure 9.20 shows small squares that represent all the spot colors from the PANTONE FORMULA GUIDE. We have seen in this chapter that a spot color can be



(a) (b)

Figure 9.21 (a) Many spot colors can be realized by a fixed, expanded gamut ink set, (b) which avoids time consuming and costly press wash-ups. *Source:* Esko. Reproduced with permission of Esko.

reproduced in a traditional manner with a separate spot channel printing plate and ink, which is an expensive and time consuming process. Simulating a spot color, however, is generally much more convenient and offers considerable time and cost savings.

Only spot colors that are in gamut can be properly simulated, therefore the number of in-gamut spot colors is dependent on the size of the print gamut. The largest print gamut in Figure 9.20 is due to a CMYKOGV print process, and this device can simulate nearly all the FORMULA GUIDE spot colors via simulation.

Figure 9.20 represents real data from an Epson SureColor P700 inkjet printer, however, a flexographic or offset printing press could similarly use a CMYKOGV ink set, Figure 9.21. If a printing press were to use a fixed 7-color ink set, it too could expand the colors in an image and also simulate nearly every spot color using some combination of CMYKOGV inks. Expanded gamut printing is therefore also called “fixed palette printing” because a printer can simply maintain 7 printing stations and print different spot color jobs without changing inks. The ability to run a number of different jobs with different spot colors without any press wash ups creates considerable savings in terms of less spot color inks, plates and inventory.

In a commercial environment, every minute a press is not running is expensive downtime. By using a CMYKOGV inkset, printers do not have to use separate spot color inks for separate jobs, they are able to use a single ink set which increases productivity of their presses by enabling ganging of jobs on press and continuous operation without clean up and ink change between jobs, Figure 9.21.

Expanded gamut printing reduces press variability and improves quality control. In CMYK printing the colorants are very far apart, Figure 9.22a. To create a yellow color in a CMYK system we must use cyan, magenta and yellow inks. Cyan, for example is a very blue color, the opposite of yellow and far away from yellow at the opposite end of the diagram, so even a small amount of variation on press will have a large impact on the printed color.

In expanded gamut printing a color is made from three very close-together colorants, Figure 9.22b. Consider the same yellow color, this could be made from the three nearest

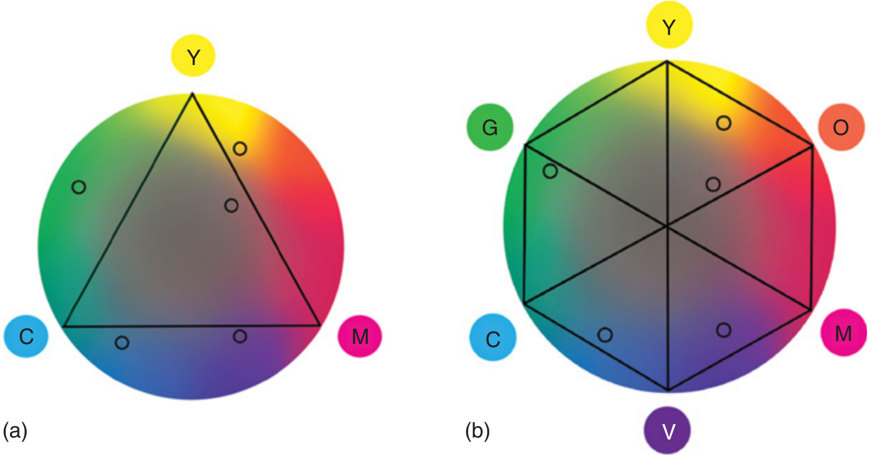


Figure 9.22 (a) Spot colors (small circles) are often outside the CMYK gamut. (b) The expanded gamut of a CMYKOGV ink set, enables realization of many more spot colors. In CMYKOGV printing, it is very beneficial that each spot color is made from three, very near, base colorants.

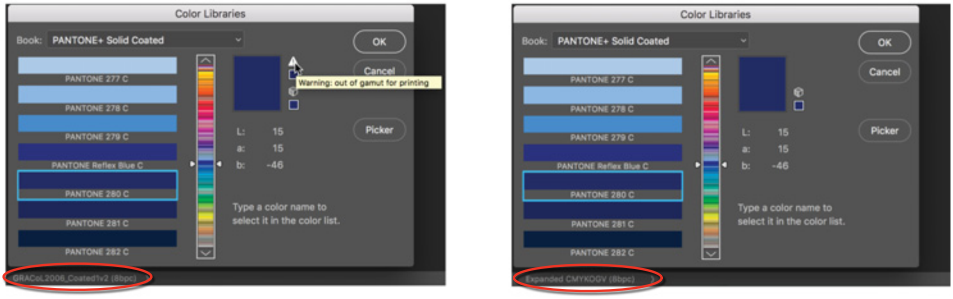
colorants, perhaps – green, yellow and orange. A shift in any of these colorants is not going to make as much difference because all three of these colorants naturally constitute yellow. In expanded gamut printing the three nearest colorants are used to create a color, and as the colorants are of a similar hue, a printing process is much easier to control.

To illustrate that an extended gamut ink set allows for much better process control during printing consider the PANTONE EXTENDED GAMUT Guide, described earlier. *Note that any swatch in the guide is printed with a maximum of three colorants* in accordance with Figure 9.22b. A randomly selected PANTONE EXTENDED GAMUT Guide was measured using a spectrophotometer. The measured L*a*b* values for different swatches agree with the L*a*b* values from the Photoshop digital library to within 1–2 ΔE. The EXTENDED GAMUT Guide was printed at a conventional print shop using standard equipment, therefore these measurements indicate impressive process control, where the accuracy of the commercial high-speed offset printing is on a par with a contract color proof. The reader can also easily conduct this test to verify this claim.

A print process characterization test chart, such as the CMYK IT8.7/4 usually needs to include a reasonable sampling of CMYK primary and overprint patches. It is important to note that in CMYOGV printing, there is no requirement to create a test chart with every combination of the seven colors, because all seven colors are never used simultaneously. Every swatch in the PANTONE EXTENDED GAMUT Guide is made with a maximum of three inks.

Expanded gamut printing allows for ink savings. As the colorants are nearby, they do not have to “fight” so much to create a color. Note that cyan ink is pulling the color in an opposite direction to yellow. Some of its efforts are wasted in this “tug of war”. Expanded gamut printing uses nearby colorants which saves ink, and the reduction in ink volume contributes to improved color stability (as there is less ink to drift), and quicker dry times.

Expanded gamut printing is now offered by every type of printing system today, including for example the HP Indigo 10000 digital press and the Epson SureColor P7000



Book: PANTONE+ Solid Coated

Warning: out of gamut for printing

L: 15
a: 15
b: -46

Type a color name to select it in the color list.

GRACoL2006_Coated1v2 (8bpc)

Book: PANTONE+ Solid Coated

L: 15
a: 15
b: -46

Type a color name to select it in the color list.

Expanded CMYKOGV (8bpc)

Figure 9.23 Photoshop provides a gamut warning for out-of-gamut spot colors that is dependent on the chosen printing process. PANTONE 280 C is out of gamut of GRACoL 2006, but is within gamut of a CMYKOGV print process.

inkjet printer. There are many software systems that support expanded gamut printing as described in the next section.

9.6 Software Solutions for Spot Colors and Expanded Gamut Printing

There are many software solutions that deal with spot colors and expanded gamut printing. There are many products that allow the user to manage and process spot color information. We consider some examples in this section.

9.6.1 Gamut Warning in Adobe Photoshop

It is useful if a designer or graphic artist can see if a spot color is in or out of gamut at the design stage of a project. Photoshop and other Adobe applications show via a warning symbol if the selected spot color is in or out of gamut of the chosen print process, Figure 9.23.

Photoshop provides a gamut warning for out of gamut spot colors that is dependent on the active ICC profile. PANTONE 280 C is out of gamut of the GRACoL 2006 print process, but if the designer requires this spot color to be accurately reproduced they can confirm that it is in gamut of a CMYKOGV print process.

A designer can see the warning and also see a comparison between the spot color and its CMYK equivalent as side-by-side patches.

9.6.2 Using PANTONE Color Manager

The PANTONE Color Manager is a product that costs $49, or is available free with purchase of a swatch book, Figure 9.24.

The PANTONE Color Manager can show via an out of gamut warning symbol which of the spot colors in a library are out of gamut of the print process. In Figure 9.24, notice that many spot colors are out of gamut on a GRACoL 2006 printing process, while many more spot colors are in gamut and can be accurately reproduced on the Epson SureColor P9000 inkjet printer with CMYKOGV inks. The Color Manager shows split colors for

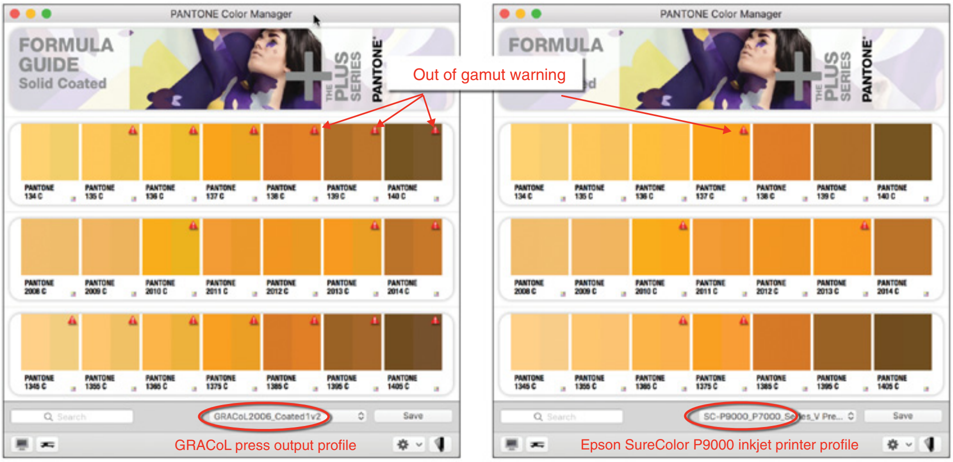

PANTONE Color Manager
FORMULA GUIDE
Solid Coated
THE PLUS SERIES
PANTONE
Out of gamut warning
PANTONE 134 C
PANTONE 135 C
PANTONE 136 C
PANTONE 137 C
PANTONE 138 C
PANTONE 139 C
PANTONE 140 C
PANTONE 2008 C
PANTONE 2009 C
PANTONE 2010 C
PANTONE 2011 C
PANTONE 2012 C
PANTONE 2013 C
PANTONE 2014 C
PANTONE 1345 C
PANTONE 1355 C
PANTONE 1365 C
PANTONE 1375 C
PANTONE 1385 C
PANTONE 1395 C
PANTONE 1405 C
Search
GRACoL2006_Coated1v2
Save
GRACoL press output profile
PANTONE Color Manager
SC-P9000_P7000_Series_V Pre...
Save
Epson SureColor P9000 inkjet printer profile

Figure 9.24 The PANTONE Color Manager is a $49 software product that has many useful features, including an out of gamut warning and visual predictor.

each spot color, simulating on the left the spot color and on the right the realization of this color in the chosen print process.

The PANTONE Color Manager can be used to export any of the PANTONE Digital Color Libraries for inclusion in Adobe Applications, so for example a user can update their Photoshop libraries with the new EXTENDED GAMUT Guide using the Color Manager.

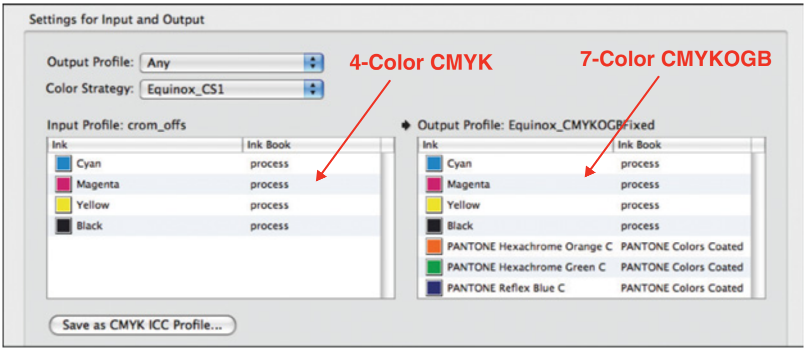
The Color Manager allows export of the Digital Color Libraries, which allows users access to the (long-hidden) list of L*a*b* values for a digital library.

9.6.3 Color Conversion with Esko Equinox

Esko Equinox is a suite of applications and software plug-ins that deal with color and expanded gamut technologies. Equinox is used as an example here as it illustrates the main components of any expanded gamut solution.

One of the basic parameters for an expanded gamut workflow is shown in a dialog for an Equinox color strategy, Figure 9.25. The figure shows how four-color CMYK images will be converted to seven-color CMYKOGB process. Expanded gamut solutions will generally support five, six, or seven inks.

Equinox tools allow for many spot color conversions and image conversions. RGB or CMYK images, for example, can be converted to seven color separations using Esko Equinox plug-ins to Adobe Photoshop, Figure 9.26. The plug-in allows the user to create a colorimetric transform, retaining the source image colors, or alternatively it is possible to selectively and artificially expand the image's gamut. Esko's Equinox is an extensive technology platform, and only a small part of Equinox has been described here to provide the reader with a feel for the types of tools that they should expect to meet in any expanded gamut solution.



4-Color CMYK

7-Color CMYKOGB

Settings for Input and Output

Output Profile: Any

Color Strategy: Equinox_CS1

Input Profile: crom_offs

Ink	Ink Book
🟦 Cyan	process
🟥 Magenta	process
🟨 Yellow	process
⬛ Black	process

Output Profile: Equinox_CMYKOGBFixed

Ink	Ink Book
🟦 Cyan	process
🟥 Magenta	process
🟨 Yellow	process
⬛ Black	process
🟧 PANTONE Hexachrome Orange C	PANTONE Colors Coated
🟩 PANTONE Hexachrome Green C	PANTONE Colors Coated
🟦 PANTONE Reflex Blue C	PANTONE Colors Coated

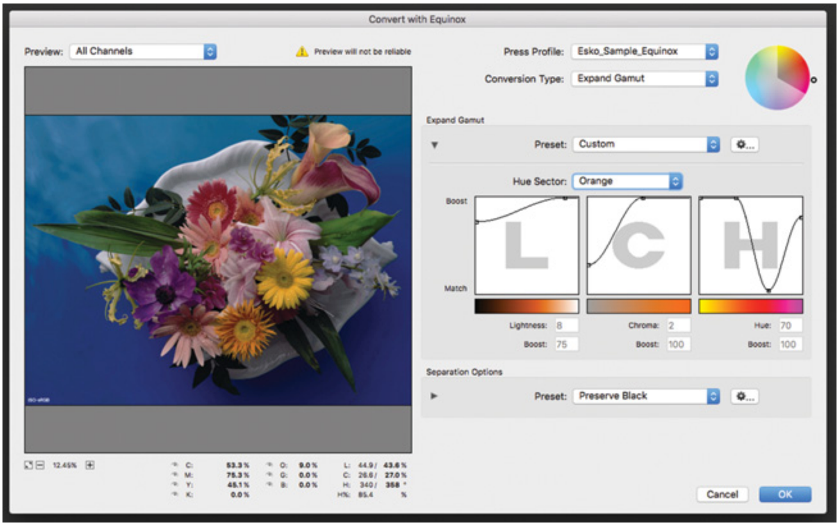
Figure 9.25 An expanded gamut system, such as Esko's Equinox must establish source CMYK and optimum destination CMYKOGB colorants.

9.6.4 Gamut Calculation in Esko Color Engine Pilot

With the increasing use of expanded gamut workflows, the management and prediction of in-gamut colors is critical information that is relevant to all parties, from content creator to prepress and printer. In this section we see how the number of in-gamut spot colors can be calculated by Esko's Color Engine Pilot, Figure 9.27.

As device color gamut information is intrinsically stored within the structure of an ICC profile this information becomes readily available to any software utilizing that profile. One easy metric to evaluate is the percentage of spot colors that are in-gamut.

The percentage of in-gamut PANTONE spot colors is a simple metric and a single number that can be easily quoted, and, is comprehensible by the average user. If a device



Convert with Equinox

Preview: All Channels

⚠ Preview will not be reliable

Press Profile: Esko_Sample_Equinox

Conversion Type: Expand Gamut

Expand Gamut

Preset: Custom

Hue Sector: Orange

Lightness: 8 Boost: 75

Chroma: 2 Boost: 100

Hue: 70 Boost: 100

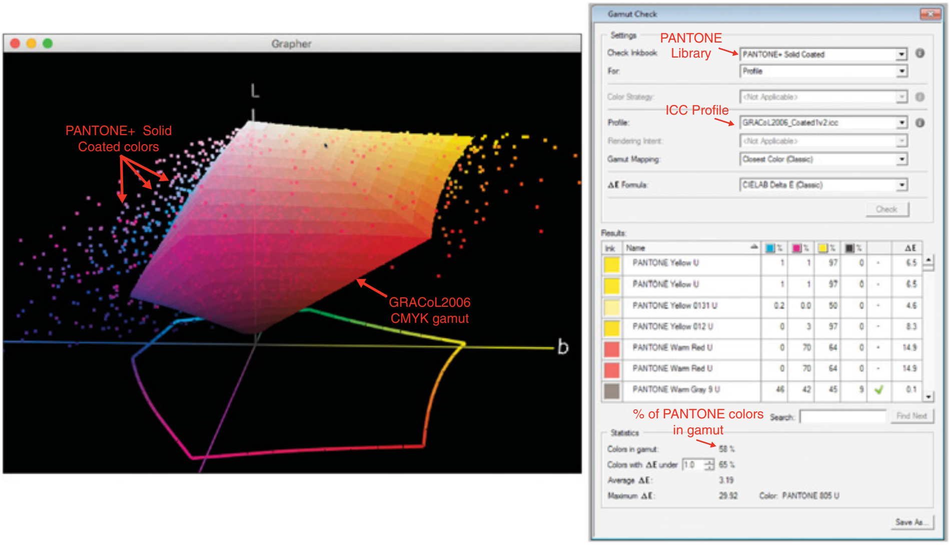
Separation Options

Preset: Preserve Black

12.45%

```
C:   53.3 %   O:  9.0 %   L:  44.9 /  43.6 %
M:   75.3 %   G:  0.0 %   C:  26.6 /  27.0 %
Y:   45.1 %   B:  0.0 %   H:  340 /   358 °
K:    0.0 %               H%: 85.4        %
```

Figure 9.26 The Esko Equinox Photoshop plug-in enables the user to convert CMYK or RGB images to an expanded gamut ink set and to selectively and artificially expand the image's gamut.



Settings

Check Inkbook: PANTONE+ Solid Coated
For: Profile
Color Strategy: <Not Applicable>
Profile: GRACoL2006_Coated1v2.icc
Rendering Intent: <Not Applicable>
Gamut Mapping: Closest Color (Classic)
ΔE Formula: CIELAB Delta E (Classic)

Results:

Ink	Name	■ %	■ %	■ %	■ %		ΔE
🟨	PANTONE Yellow U	1	1	97	0	-	6.5
🟨	PANTONE Yellow U	1	1	97	0	-	6.5
🟨	PANTONE Yellow 0131 U	0.2	0.0	50	0	-	4.6
🟨	PANTONE Yellow 012 U	0	3	97	0	-	8.3
🟥	PANTONE Warm Red U	0	70	64	0	-	14.9
🟥	PANTONE Warm Red U	0	70	64	0	-	14.9
🟫	PANTONE Warm Gray 9 U	46	42	45	9	✓	0.1

Search:

Statistics

Colors in gamut: 58 %
Colors with ΔE under 1.0: 65 %
Average ΔE: 3.19
Maximum ΔE: 29.92 Color: PANTONE 805 U

Figure 9.27 Esko Color Engine Pilot shows that 56% of the PANTONE Coated library is in-gamut of a GRACoL CMYK printing process. This is visually confirmed by evaluation of the spot colors and ICC profile gamut in L*a*b*.

is able to achieve 50%, 60%, or 70% of a given PANTONE library this is directly related to the underlying color gamut of the system under consideration and is metric that has direct practical applications – if a spot color is in-gamut this means that it can be reproduced accurately on the target printing system, without spot color inks.

Commercial expanded gamut systems tend to use the in-gamut spot colors number to describe their gamut capabilities, for example, current claims for expanded gamut systems often claim to "hit 90% of spot colors."

Figure 9.27, shows the concept of in-gamut spot colors in an L*a*b* diagram. The small squares represent the individual swatch colors from the PANTONE Coated library. The GRACoL 2006 offset press gamut is shown as a transparent volume. There are many spot colors that are inside the press volume. These spot colors can be simulated by the CMYK print process, but there are also many spot colors that are outside the press gamut.

A useful metric is a count of the in-gamut spot colors. Figure 9.27 shows a dialog from Esko Color Engine Pilot. In Color Engine Pilot a PANTONE library is selected at the top of the dialog, next the output profile for the print process is chosen. In the figure, we see that the GRACoL 2006 CMYK print process is able to reproduce 56% of the PANTONE Coated library. Color Engine Pilot is an example of how vendors are now providing an easy to use dialog to compute in-gamut spot colors for a given print process.

9.7 Summary

In this chapter we focussed on the components of the PANTONE MATCHING SYSTEM (PMS). In particular we saw that the PMS system consists of the guide books, digital color libraries and ink formulation recipes. It was shown that when all parties are on board, and a PMS system is implemented and used correctly, spot colors can be efficiently and accurately managed from designer to prepress to printing. An advantage of the PMS system is that there are no surprises, the client can be presented with press results that match the color they approved from a swatch book.

We note that the CMYK tint values printed in the Pantone guides are largely irrelevant. The color appearance of the swatches is very important but the CMYK values listed in the COLOR BRIDGE and the CMYKOGV values provided in the EXPANDED GAMUT Guide can largely be ignored.

The parts of the Pantone Matching System have not always been perfectly aligned, there have been large variations between the swatch books and differences between the swatch books and the digital libraries. Pantone has greatly improved its processes and measurement of the latest EXPANDED GAMUT Guide corroborate these process improvements.

An important observation is that there is no barrier to incorporating the Pantone proprietary system into an ICC color management system. Pantone colors are specified in terms of L*a*b* which allows spot colors to be incorporated into color management workflows using ICC output profiles.

This chapter described different methods to print spot colors. Traditionally in flexography and offset printing, spot colors have been reproduced using a spot color ink. It is not necessary to use a spot color ink to print a spot color and in general we see that it is possible to print a PANTONE-specified spot color by simulating the color with CMYK/CMYK+ inks, as available in the printing process. An issue with spot color simulation in CMYK has been that the CMYK gamut for many devices, is able to reproduce perhaps only 50–60% of a spot color library. There are many spot colors a designer or brand owner may have wanted to use, which in a CMYK process is only possible with an expensive spot color workflow. The emergence of an extended gamut ink set means that it is no longer necessary to employ a spot color workflow, as nearly 90% of the spot colors can be adequately simulated by the use of additional orange, green, and violet inks

Spot color matching on digital presses is often been poorly implemented. This chapter presented a number of tools available to the digital press operator to better manage colors by, for example, printing a custom swatch book.

There are new tools and technologies from most of the major companies to support expanded gamut design and layout, processing, separation, proofing, and printing. Workflow systems and RIPs are able to convert a spot color into a CMYKOGV formulation, an example of which is Esko's Equinox software suite.

A major theme in this chapter are the concepts and technologies surrounding expanded gamut printing. A primary motivation for expanded gamut printing is that the expanded gamut can accommodate many more spot colors with a fixed ink palette, removing the need to change inks on press for individual spot color jobs.

There are competing pressures on commercial printing today – to improve (increase) color gamut and at the same time reduce costs and reduce time in the plant. Using an expanded gamut ink set meets these requirements. In simple terms, it is more economical to use a fixed color palette rather than wash up spot colors for individual jobs.

There are a number of print-related benefits of expanded gamut printing, such as the reduction in number of press wash ups, ability to gang jobs, better process control on press, reduced ink usage, etc. Expanded gamut printing is readily available in all aspects of prepress, printing, and proofing, from swatch books to workflow software to digital presses and inkjet proofers.

Expanded gamut printing allows packaging and label printers to match more brand colors without the production overheads of conventional spot color printing.

Color management of spot colors and expanded gamut printing continue to be important specialist topics in practical color management.

10

XML and Color Management

Objectives

- Explain HTML and XML markup languages.
- List XML design goals, such as simplicity and ease of use.
- Describe XML basics – declaration, elements, attributes, and schema.
- Describe application of XML in color management applications.

10.1 Introduction

This chapter provides an introduction and overview to XML technology as applicable to color management applications. XML (eXtensible Markup Language) is widely used in all modern computer and IT applications and now also powers every aspect of color management and print production. This chapter provides the reader with the tools and information necessary to read and understand XML as applicable to prepress applications.

Today, many computer systems and databases contain data in proprietary, encrypted formats. One of the most time-consuming challenges for developers is to exchange data between incompatible systems, and sometimes there are even issues between different parts of the same system. A benefit of XML is that it provides a non-proprietary way of storing data, which makes it much easier to create and share data between different applications.

XML is a very easy technology for non-technical audiences because there is no requirement to learn a programming language. There are no encrypted files or special software needed to implement XML and it can be viewed using any browser – Firefox, Chrome, Internet Explorer, Safari, etc. XML is written in easy to read plain text, using English words. XML is related to another well known markup language – HTML – as used in Internet applications.

In this chapter we describe the basic building blocks and components of the XML language, including the declaration, elements, attributes, schema and namespaces.

In this chapter we consider a number of color management applications of XML. We see that the Windows Color System (WCS) is XML based. The emerging ICC specification, iccMAX, uses XML for profile connection data. The Color eXchange

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Format (CxF) uses XML to communicate spot color information in PDF workflows. All X-Rite i1Profiler data files are stored as XML. Heidelberg uses XML to communicate ink key information and Kodak Preps uses XML for imposition and print automation.

It is not necessary to read an XML file to get color management to work, and most users should never have to read XML code. In the long term it is envisaged that XML will become an "under the hood" technology and there will be little need to open and inspect an XML file. However, during these early days of XML implementation, it is often necessary to open and analyze an XML file as is done throughout this chapter.

XML is not specific to color management or prepress; it is used by the wider computer and IT communities. This means that color management applications do not need to develop their own tools but can piggy back on the mature systems that already exist. Adopting an XML platform for color management applications provides instant access to the whole world of computer-based XML tools, such as XML editors and validators.

XML technology is ubiquitous in all technology areas, where it brings many advantages in terms of automation, efficiency of a common file format, interoperability and a simple, human readable format. Today every owner, manager, prepress operator, production coordinator, and salesperson should understand some simple XML basics in order that we can make educated, well-informed decisions. When making, for example, a purchasing decision it is important to ensure the product or products are XML compliant.

XML is an enabling technology that powers our computer-based, digital economy, today and into the future.

10.2 Markup Languages

Markup languages are the fundamental method for data storage and information interchange in most modern, computer-based technologies. SGML (Standard Generalized Markup Language) was introduced in the 1980s and is the parent form of the markup language. Most of us have met HTML (Hypertext Markup Language) which is the markup language used for encoding web-based applications. XML (eXtensible Markup Language) is a markup language, however unlike HTML that has pre-defined tags, XML is an extensible language which means that it can be extended.

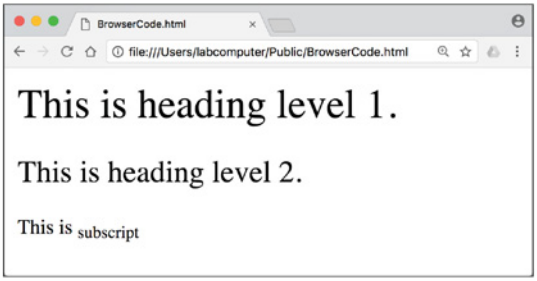
The concept of a markup language is that information is stored within opening and closing tags, so the content is "marked up." The markup tags have special meaning when interpreted by an appropriate processor, Figure 10.1. In HTML, the tag, <h1>, is interpreted by a browser, in this example the browser is Google Chrome, which displays the text as a pre-defined, large, font. Other opening and closing tags could be <h2> which is a smaller heading, or <sub> which is interpreted and displayed as subscript text. Each open tag is followed by a closing tag, indicated by a forward slash.

A markup language focusses on data and data storage, and the primary purpose of a markup language is to create a structured document. The interpretation and rendering of the information within the markup tags is left to a processor, in this example, a web browser. The separation of content and formatting is very useful, for example a web page

```
<h1>This is heading level 1.</h1>

<h2>This is heading level 2.</h2>

This is <sub>subscript</sub>
```



This is heading level 1.

This is heading level 2.

This is subscript

Figure 10.1 HTML is a markup language with opening and closing tags that can be processed and displayed by a browser such as Google Chrome.

can be re-formatted to a different color scheme without having to alter the underlying file content.

10.3 XML Design Principles

XML was developed under the auspices of the World Wide Web Consortium (W3C). From the outset the W3C established primary design goals that have guided the evolution and development of XML. These design principles are the primary reason for the success of XML in so many of today's technology systems.

The W3C XML design goals are:

1) *XML shall be easily usable over the Internet.* Since the Internet is one of the major sources of information sharing, XML has to be compatible with the major Internet protocols such as HTTP and MIME.
2) *XML shall support a wide variety of applications.* XML should not be limited to the Internet, it should also be effective for other applications, such as databases, spreadsheets, financial transactions, EPUBs, spot color data files, etc.
3) *XML shall be compatible with SGML.* Because XML is a subset of SGML, many of the software tools developed for XML should be adaptable for its SGML predecessor.
4) *It shall be easy to write programs that process XML documents.* One of HTML's greatest strengths is its simplicity. XML should emulate HTML by making it easy for even non-programmers to read and write XML code. A number of examples of code are presented in this chapter that demonstrate the simplicity of XML.
5) *The number of optional features in XML must be kept to the absolute minimum, ideally zero.* HTML supports a wide range of optional features, which reduces interoperability. XML should remove this aspect of HTML, which would make it a more suitable development tool for real time applications.
6) *XML documents should be clear and easily understandable by non-programmers.* Like HTML documents, XML documents should be text files that are easy to read in any browser or text editor. The contents of an XML document should follow a logical, tree-like structure with indented structures as shown in this chapter.

7) *XML should enjoy rapid acceptance.* XML is only going to be useful if it is adopted before other competing technology solutions, and if it becomes a viable alternative to HTML for web-based applications. Happily this is the case.
8) *The design of XML shall be exact and concise.* The premise of ICC color management is predictable results, similarly, if XML is precise, this ensures all XML applications will behave the same way.
9) *XML documents shall be easy to create.* For XML to be practical, XML documents needed to be as easy to work with and create, as editing an HTML document. This principle means that any technology using XML has a much more rapid development and debugging cycle.
10) *Terseness in XML markup is of minimal importance.* This is a nod to programmers not to use x1, y1, z1, but it is important to make the code understandable, using meaningful English words. We soon discuss real examples using XML element names, e.g. CustomerInfo, RedPrimary, MeasurementData, ProfileVersion, PreferredCMMType, etc.

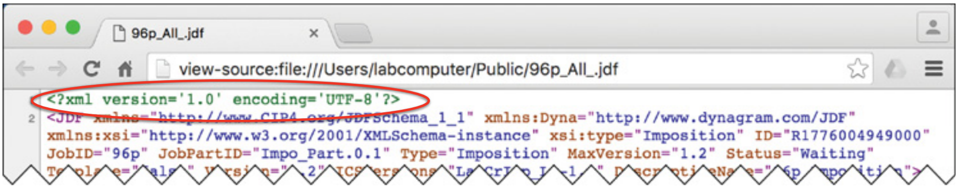
Throughout this chapter we see implementation and application of these design principles.

10.4 Basics of XML

In this section we consider the basics of XML, starting with the *declaration* that is the first line of an XML file. *Elements* make up the basic building blocks of XML and are used to store data. Further parameters can be added to an element using a construct called an *attribute*. And we see that elements and attributes can relate to a specific "vocabulary" for each industry, called a *schema*. A schema is implemented via a *namespace* instruction within the XML file. We now explain each of these items and their use.

10.4.1 Declaration

The *declaration* is always the first line in an XML document, Figure 10.2. Every XML document must have a declaration, it tells the processor-what follows is written in XML. If an XML file is opened in a web browser, as shown in the figure, the browser is alerted to the XML content by the declaration and then knows to display the content with color coding and indentation to make the XML easier to read.



```
<?xml version='1.0' encoding='UTF-8'?>
<JDF xmlns="http://www.CIP4.org/JDFSchema_1_1" xmlns:Dyna="http://www.dynagram.com/JDF"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:type="Imposition" ID="R1776004949000"
JobID="96p" JobPartID="Impo_Part.0.1" Type="Imposition" MaxVersion="1.2" Status="Waiting"
```

Figure 10.2 The declaration is always the first line in an XML document, this identifies the XML code to a web browser.

There are three parts to a declaration, a typical example may be

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
```

There are default values for these parameters, so if they are not provided a default value is assumed. In the real example shown in Figure 10.2, there is no entry for standalone, so the default value of "no," is assumed. Note that the term "xml" is a reserved element name with special significance, the declaration is the only place in an XML file that can start with the term "xml."

10.4.2 Elements

The data in an XML document is contained within a structure called an *element*. Elements contain an opening tag and a matching closing tag. The closing tag is indicated by a forward slash. The opening and closing tags must match exactly, and are case sensitive. Content is stored in between the opening and closing tags. The whole structure – the opening and closing tags and the content – is called an XML element. The following are XML element examples:

```
<Address> 25 Birch Drive </Address>
<Magenta> 75 angle </Magenta>
```

In these examples, <Address> and </Address> are the opening and closing parts of the element and "25 Birch Drive" is the content of the element, similarly Magenta is the element name and "75 angle" is the content of the element.

Elements can be empty, for example, if we have no details for the address. There are two ways to write an empty element – it is possible to simply leave the content blank, or more commonly the following shortcut form is used.

```
<Address></Address>      An empty element
<Address/>               Shortcut version of an empty element
```

In practice the second, shorter way is used in most real world XML applications.

XML elements can be nested. In the following XML code, we see nested elements. Nested elements are children of their parents, and when nested to the same level, the elements are siblings.

```
<ColorCMYK>                      Parent element
      <Cyan>0</Cyan>             Child element
      <Magenta>70</Magenta>      Sibling element
      <Yellow>70</Yellow>
      <Black>10</Black>
</ColorCMYK>
```

10.4.3 Attributes

Further information pertaining to an element can be stored in a structure called an *attribute*. An attribute is contained within an element's opening bracket and the attribute value is always enclosed in quotation marks. Attributes are usually features or characteristics of an element, as shown in the following example, where the attribute is shown in blue. The Address element has an attribute that indicates if the Address is residential or commercial.

```
<Address Type="textquotedblleft Residential">25 Birch
Drive</Address>
<Address Type="Commercial">45 High Tech Rd</Address>
```

An attribute can be used with an empty element. It is very common to see an attribute with an empty element, the syntax may at first appear confusing, especially if the empty element is shown in shortcut form – as is usually the case.

`<Media MediaType="Paper"></Media>`	*Empty element with attribute*
`<Media MediaType="Paper"/>`	*Empty element with attribute*

An attribute always occurs within the opening part of an element name.

10.4.4 Schema

XML is extensible which means that new elements and attributes can be created to suit the user. This flexibility creates a problem where one company may create a database and store the customer name using an element called <Name>, while another user may choose <Person> or <Contact>. When sending data between different databases the content must be mapped from one element name to another.

In order to improve interoperability different technology areas and industry groups have developed XML "vocabularies" where a technology area has agreed to use only specific element names and attributes. When all parties adhere to a specified vocabulary it increases interoperability as it enables files and data to flow freely between equipment and systems from different manufacturers.

A *schema* document is a "rule book", or "master list" of approved XML element names for a specific industry. The schema document is an external document that contains a list of approved element names and attributes and describes how they should be used and permissible values. Whole industries such as the financial or printing or news media or music industry have adopted and agreed upon different schemas. The relevant schema document is typically referenced within the first opening element of an XML file, using the xml namespace (xmlns) command. The following are all real-world schema examples for specific applications.

In Microsoft Excel we see a Microsoft schema declared for a Workbook:

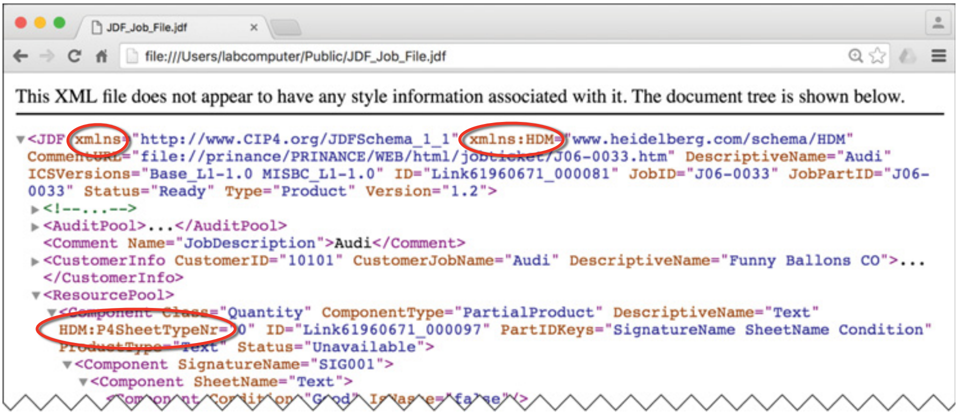
```
<Workbook xmlns="urn:schemas-microsoft-com...</Workbook>
```

In an EPUB document we see a schema declared to ensure compatibility between different tablets devices:

```
<package xmlns="http://www.idpf.org/2007"...</package>
```

In the printing industry we see a Job Definition Format (JDF) schema for print production, which is regulated by the CIP4 organization

```
<JDF xmlns="http://www.CIP4.org/JDFSchema...</JDF>
```



This XML file does not appear to have any style information associated with it. The document tree is shown below.

```
▼<JDF xmlns="http://www.CIP4.org/JDFSchema_1_1" xmlns:HDM="www.heidelberg.com/schema/HDM"
 CommentURL="file://prinance/PRINANCE/WEB/html/jobticket/J06-0033.htm" DescriptiveName="Audi"
 ICSVersions="Base_L1-1.0 MISBC_L1-1.0" ID="Link61960671_000081" JobID="J06-0033" JobPartID="J06-
 0033" Status="Ready" Type="Product" Version="1.2">
  ▶<!--...-->
  ▶<AuditPool>...</AuditPool>
   <Comment Name="JobDescription">Audi</Comment>
  ▶<CustomerInfo CustomerID="10101" CustomerJobName="Audi" DescriptiveName="Funny Ballons CO">...
   </CustomerInfo>
  ▼<ResourcePool>
    ▼<Component Class="Quantity" ComponentType="PartialProduct" DescriptiveName="Text"
     HDM:P4SheetTypeNr="0" ID="Link61960671_000097" PartIDKeys="SignatureName SheetName Condition"
     ProductType="Text" Status="Unavailable">
      ▼<Component SignatureName="SIG001">
        ▼<Component SheetName="Text">
```

Figure 10.3 A default, JDF CIP4 schema is declared and also a private, HDM, Heidelberg schema. Within the XML file, Heidelberg elements and attributes are indicated by HDM.

In color management the CxF file for encoding spot color information refers to a Color eXchange Format schema

`<CxF xmlns="http://colorexchangeformat.com/CxF3...</CxF>`

10.4.5 Private Schemas

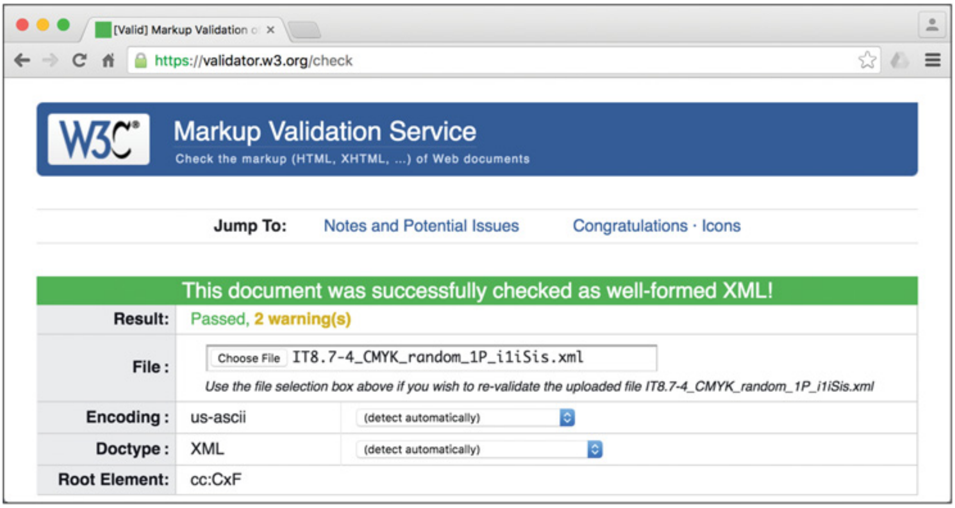
In XML, a default, public schema is allowed as well as a private schema, Figure 10.3. A particular manufacturer, in this instance Heidelberg, may not find schema elements for every conceivable equipment configuration that the vendor has to offer. Private tags are a way for a manufacturer to adhere to a common standard while still retain any features that are specific to their equipment or processes.

The very first element in an XML file is called the root element, and has special properties. Figure 10.3 shows an example XML file in which <JDF> is the root element. All elements and attributes in the XML file inherit any namespace declarations made within the root element.

In Figure 10.3 we see that the default, standard JDF schema is referenced via an xmlns command. A private Heidelberg schema is also declared. Attributes and elements in the rest of the file can use either of these schemas. When using an element, such as <AuditPool> or <CustomerInfo>, if it belongs to the default schema we can simply use the element or attribute name. When an element or attribute is from the private schema, we prefix the name with the relevant private schema, an example in this file would be <HDM:P4SheetTypeNr>. So we see that a private schema allows a vendor to work cooperatively and maintain interoperability within an industry, without sacrificing their commercial advantage.

10.4.6 Validation and Conformance

There are different levels of XML checking that range from syntax checking, to schema validation, and finally conformance to an Interoperability Conformance Specification (ICS).



Markup Validation Service

Check the markup (HTML, XHTML, ...) of Web documents

Jump To: Notes and Potential Issues Congratulations · Icons

This document was successfully checked as well-formed XML!

Result:	Passed, 2 warning(s)
File :	Choose File IT8.7-4_CMYK_random_1P_i1iSis.xml *Use the file selection box above if you wish to re-validate the uploaded file IT8.7-4_CMYK_random_1P_i1iSis.xml*
Encoding :	us-ascii (detect automatically)
Doctype :	XML (detect automatically)
Root Element:	cc:CxF

Figure 10.4 The W3C XML validator can be used to check the syntax of an X-Rite i1Profiler test chart file.

In the first instance we may be interested in *syntax checking* of an XML file. Perhaps an error has crept into the file and there is a mis-matched open and close element as shown in this line of XML code with a lower case letter.

```
<Address> 25 Birch Drive</address>
```

All current web browsers will do this level of syntax checking and when Chrome, Firefox or Safari are provided with an XML file containing a syntax error, they will stop and identify the line number on which it occurs. There are also many online tools that will check the syntax of an XML file. Figure 10.4 shows how a W3C XML validator can be used to successfully check the XML syntax of an X-Rite i1Profiler test chart reference file.

The next level of checking is called XML *schema validation*. In validation level checking we not only check the syntax of an XML file (such as the open and close brackets and capitalization) but we also confirm that all the element and attributes are in accordance with any declared schema. Syntax checking and schema validation can often be done simultaneously.

The final level of checking is *ICS conformance* – conformance to an Interoperability Conformance Specification (ICS). An ICS is a subset of XML elements and attributes that are required for a particular part of a system.

As an example, consider the latest ICC specification, iccMAX. Not every feature of the iccMAX specification needs to be implemented, so there may be an ICS document for specific application areas such as displays, packaging, medical imaging, fine art, three-dimensional printing, etc. Profile-making software may claim conformance by reading or creating profiles that contain a sub-set of tags as specified by a particular ICS. The approach for ICC v5 profiles is a deviation from the v2 and v4 approach where a CMM must be able to implement all profile components.

ICS documents and ICS validation ensures proper color communication and interoperability between systems. For iccMAX, conformance testing to an ICS is currently managed by the ICC Profile Assessment Working Group.

So we see that there can be different levels of checking – syntax checking, schema validation and ICS conformance. All this checking, however, does not confirm the goodness of the underlying data, i.e. there is no verification of the color information, merely that the data file is properly formed and can be communicated between color management applications. As an analogy, checking the XML tag for a customer address will only confirm that the tag contains a house number and a street name, not whether the house still exists or the resident still lives there.

10.5 Working with XML

We have described the basic building blocks and structure of XML, and essentially this is all there is to know in order to be able to open and use XML files. In this section we see how XML is used in a wide range of prepress and color management applications.

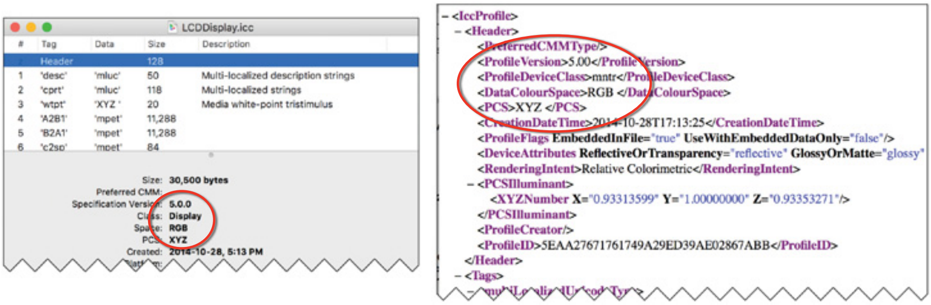
10.5.1 iccMAX

The current binary-encoded format of an ICC profile does not allow the user to easily view a profile's contents. Converting an ICC profile into XML, however, allows the user to easily open, view, and edit a profile before converting it back to a binary-file format to use in applications.

There are translators that will convert v4 and v5 ICC profiles into XML representation, Figure 10.5. The XML file uses elements and attributes to store and display the profile's contents. In the figure we see that the Version, Profile Class, Color Space, PCS, etc. of an ICC profile are displayed in ColorSync Utility, and the same data is contained and viewed in an XML file.

The purpose for converting ICC profiles into XML is to provide a human editable, text representation of ICC profile data. Profiles can be converted to a textual representation that can be easily edited using a text editor.

The iccMAX v5 ICC profile architecture builds on XML data structures in another way. Many of the iccMAX data structures can be stored, imported and exported in XML



#	Tag	Data	Size	Description
	Header		128	
1	'desc'	'mluc'	50	Multi-localized description strings
2	'cprt'	'mluc'	118	Multi-localized strings
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'A2B1'	'mpet'	11,288	
5	'B2A1'	'mpet'	11,288	
6	'c2sp'	'mpet'	84	

Size: 30,500 bytes
Preferred CMM:
Specification Version: 5.0.0
Class: Display
Space: RGB
PCS: XYZ
Created: 2014-10-28, 5:13 PM

```
- <IccProfile>
  - <Header>
      <PreferredCMMType/>
      <ProfileVersion>5.00</ProfileVersion>
      <ProfileDeviceClass>mntr</ProfileDeviceClass>
      <DataColourSpace>RGB </DataColourSpace>
      <PCS>XYZ </PCS>
      <CreationDateTime>2014-10-28T17:13:25</CreationDateTime>
      <ProfileFlags EmbeddedInFile="true" UseWithEmbeddedDataOnly="false"/>
      <DeviceAttributes ReflectiveOrTransparency="reflective" GlossyOrMatte="glossy"
      <RenderingIntent>Relative Colorimetric</RenderingIntent>
    - <PCSIlluminant>
        <XYZNumber X="0.93313599" Y="1.00000000" Z="0.93353271"/>
      </PCSIlluminant>
      <ProfileCreator/>
      <ProfileID>5EAA27671761749A29ED39AE02867ABB</ProfileID>
    </Header>
  - <Tags>
```

Figure 10.5 A v5 iccMAX profile can be displayed in ColorSync Utility (left) or converted into an XML file (right) for viewing and editing.

encoding. The iccMAX architecture supports various “profile connections” where data can be added to the color processing pipeline via XML. Examples of profile connections could be tint-based colors, spectral connections for the light source, material connections for overprint visualization, bio-markers for visualization of medical slides, spot color data, etc.

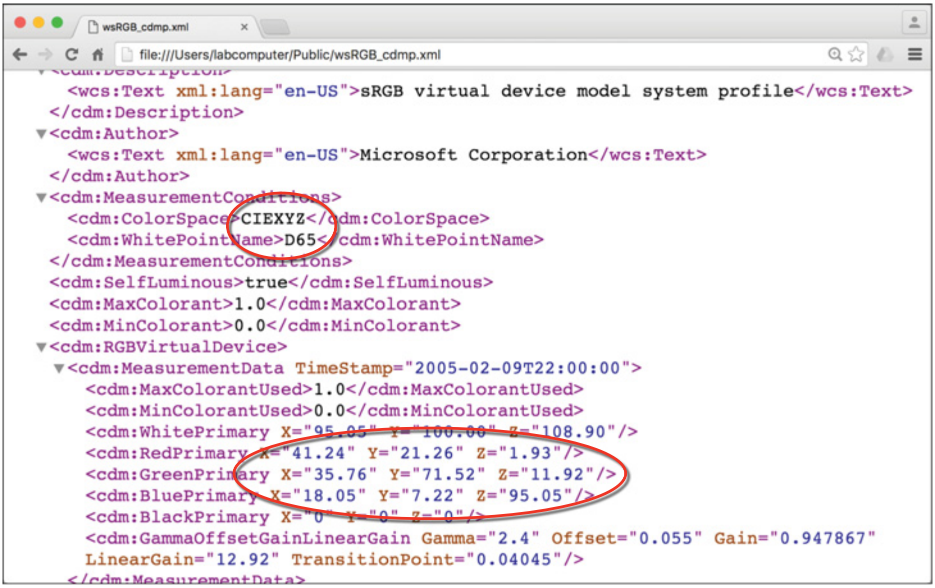
10.5.2 Windows Color System (WCS)

One of the most prominent uses of XML in color management is the Microsoft® Windows Color System (WCS). WCS was introduced in Vista™ in 2005 and has been retained in all subsequent Windows operating systems.

Microsoft continues to support conventional ICC profiles, but with Canon, has introduced a parallel, new, XML-based, color management infrastructure called the Windows Color System (WCS). The use of XML allows independent software and hardware vendors to easily write programs for WCS, and XML makes it easy for developers to add modules and extend the color management capabilities of the system.

The WCS system consists of a color device model, a color appearance model, and a gamut mapping model. These models are all encoded in XML. The different parts of the system are brought together in the Color Infrastructure and Translation Engine (CITE) which is used to convert image pixel data. Figure 10.6 shows the first part of this system – a color device model profile.

Figure 10.6 shows a Color Device Model Profile (cdmp) for sRGB, a widely used, common, default color space profile. This file contains color data within XML elements, for example, there are elements and nested elements to specify CIEXYZ and the D65 illuminant. Data, such as the XYZ device chromaticities, are stored in attributes (in quotation marks).



```
▼<cdm:Description>
    <wcs:Text xml:lang="en-US">sRGB virtual device model system profile</wcs:Text>
  </cdm:Description>
▼<cdm:Author>
    <wcs:Text xml:lang="en-US">Microsoft Corporation</wcs:Text>
  </cdm:Author>
▼<cdm:MeasurementConditions>
    <cdm:ColorSpace>CIEXYZ</cdm:ColorSpace>
    <cdm:WhitePointName>D65</cdm:WhitePointName>
  </cdm:MeasurementConditions>
  <cdm:SelfLuminous>true</cdm:SelfLuminous>
  <cdm:MaxColorant>1.0</cdm:MaxColorant>
  <cdm:MinColorant>0.0</cdm:MinColorant>
▼<cdm:RGBVirtualDevice>
  ▼<cdm:MeasurementData TimeStamp="2005-02-09T22:00:00">
      <cdm:MaxColorantUsed>1.0</cdm:MaxColorantUsed>
      <cdm:MinColorantUsed>0.0</cdm:MinColorantUsed>
      <cdm:WhitePrimary X="95.05" Y="100.00" Z="108.90"/>
      <cdm:RedPrimary X="41.24" Y="21.26" Z="1.93"/>
      <cdm:GreenPrimary X="35.76" Y="71.52" Z="11.92"/>
      <cdm:BluePrimary X="18.05" Y="7.22" Z="95.05"/>
      <cdm:BlackPrimary X="0" Y="0" Z="0"/>
      <cdm:GammaOffsetGainLinearGain Gamma="2.4" Offset="0.055" Gain="0.947867"
      LinearGain="12.92" TransitionPoint="0.04045"/>
    </cdm:MeasurementData>
```

Figure 10.6 The Windows Color System (WCS) is fully XML. Here we show an sRGB Color Device Model Profile that uses XML elements and attributes.

The color device model, color appearance model, and gamut mapping model are all encoded in XML and are based upon, open, published XML schemas. The schemas are invoked via the xmlns command. Using a published schema makes it easy for third parties to edit, verify, understand, and extend the data modules.

Measurement data from a measuring instrument can be mapped directly from a measurement XML file into a WCS XML file. Colors can be measured by a color measurement instrument, such as a colorimeter or spectrophotometer, and the results communicated via an XML data stream. The data transfer via XML can support devices with automatic built-in calibration, and offer convenience to the user allowing a device to re-characterize or re-calibrate itself. New media can be introduced and effortlessly characterized by XML-powered, plug-n-play connectivity.

XML significantly improves the ease with which profiles can be edited, both manually and automatically. Photographers and graphic artists can directly examine the values in an WCS XML profile to ensure that the profile values are appropriate.

The extensibility of XML future-proofs the architecture. By providing support for plug-in modules, future changes to color processing can be provided that are compatible with existing profiles. XML opens the opportunity for vendors to add utilities and provide extensions and solutions targeted at niche markets.

Within the operating system, changes can be made to the CITE CMM. While the Windows Color System is infrequently used in professional color management circles, by choosing XML, Microsoft has made the right technology choice for WCS encoding.

10.5.3 Color Exchange Format (CxF)

Color Exchange Format (CxF) is an XML format for storing and exchanging spectral measurement data for spot color inks. CxF was developed by GretagMacbeth (now X-Rite) and was originally used for information exchange between their instruments and software.[1] X-Rite provided the CxF format to the wider community and it has now been adopted as an international standard – ISO 17972.

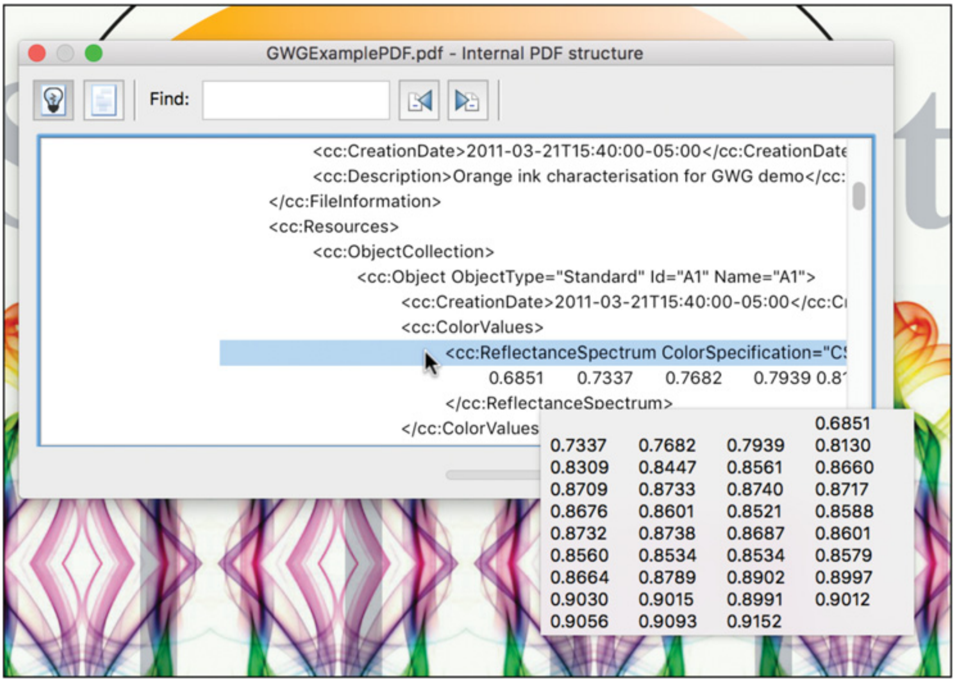
A CxF file can be stored in emerging PDF file formats so that everybody can easily access and use the information, Figure 10.7. For CMYK/RGB components in a PDF file, color can be managed using conventional ICC profiles, but for spot colors or spot color tints, often specially measured spectral data is needed to compute accurate printing instructions based on the final printing parameters.

In Adobe Acrobat Pro, via *Preflight>Options>Browse Internal PDF Structure*, we can see the CxF-encoded spectral data within the OutputIntent part of the file, Figure 10.7. This metadata clearly shows human readable text and consists of XML elements and attributes. Color servers or ink formulation systems are able to parse and readily access this information.

CGS ORIS has created a program called CxF Toolbox, Figure 10.8. CxF Toolbox converts measurement data from a measuring instrument into CxF and can embed that data into a PDF file or export it to the Adobe suite of applications via an .ase (Adobe Swatch Exchange) file.

---

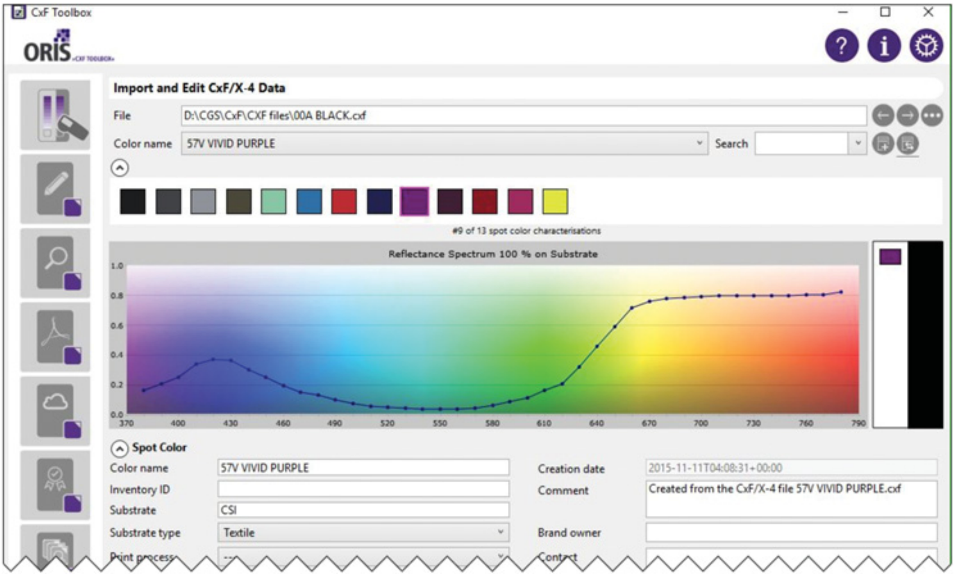
[1] *Color Exchange Format 3.0 – A standard for exchange of color information, X-Rite, Incorporated, Nov, 2009.*


GWGExamplePDF.pdf - Internal PDF structure
Find:

```
          <cc:CreationDate>2011-03-21T15:40:00-05:00</cc:CreationDate
          <cc:Description>Orange ink characterisation for GWG demo</cc:
      </cc:FileInformation>
      <cc:Resources>
          <cc:ObjectCollection>
              <cc:Object ObjectType="Standard" Id="A1" Name="A1">
                  <cc:CreationDate>2011-03-21T15:40:00-05:00</cc:Cr
                  <cc:ColorValues>
                      <cc:ReflectanceSpectrum ColorSpecification="C
                          0.6851    0.7337    0.7682    0.7939 0.8
                      </cc:ReflectanceSpectrum>
                  </cc:ColorValues
```

```
                                    0.6851
0.7337    0.7682    0.7939    0.8130
0.8309    0.8447    0.8561    0.8660
0.8709    0.8733    0.8740    0.8717
0.8676    0.8601    0.8521    0.8588
0.8732    0.8738    0.8687    0.8601
0.8560    0.8534    0.8534    0.8579
0.8664    0.8789    0.8902    0.8997
0.9030    0.9015    0.8991    0.9012
0.9056    0.9093    0.9152
```

Figure 10.7 Adobe Acrobat Pro shows spot color spectral data stored as CxF XML metadata.


CxF Toolbox
ORIS CXF TOOLBOX
Reflectance Spectrum 100 % on Substrate
1.0
0.8
0.6
0.4
0.2
0.0
370
400
430
460
490
520
550
580
610
640
670
700
730
760
790

Import and Edit CxF/X-4 Data

File: D:\CGS\CxF\CXF files\00A BLACK.cxf

Color name: 57V VIVID PURPLE

Search:

#9 of 13 spot color characterisations

Spot Color

Color name: 57V VIVID PURPLE

Inventory ID:

Substrate: CSI

Substrate type: Textile

Print process: ---

Creation date: 2015-11-11T04:08:31+00:00

Comment: Created from the CxF/X-4 file 57V VIVID PURPLE.cxf

Brand owner:

Contact

Figure 10.8 CGS ORIS has released CxF Toolbox that creates a CxF file from measurement data and creates swatches for the Adobe suite of applications.

CxF is described in ISO 17972 which creates openness and standardization, and the technology is even more useful as it is enjoys the strengths and universal acceptance of XML.

10.5.4 X-Rite i1Profiler

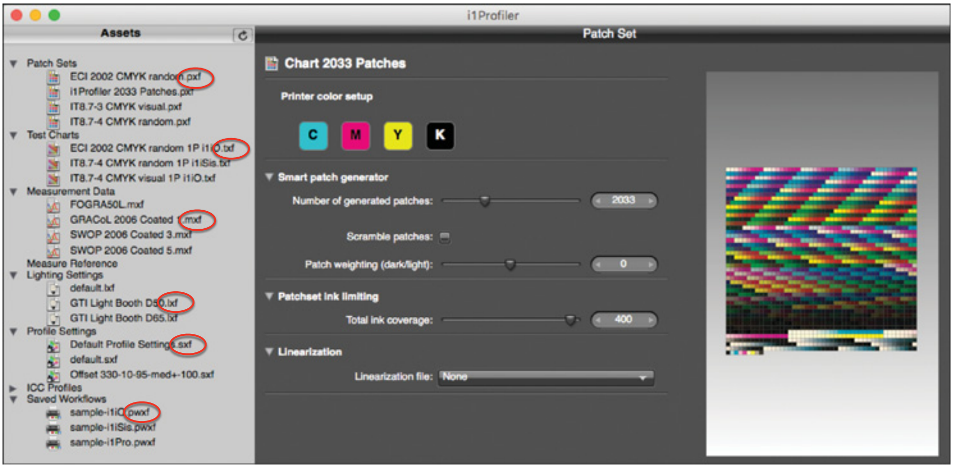
X-Rite i1Profiler is a popular program that allows for creation of ICC profiles and other color management related operations. All of the asset files within X-Rite i1Profiler are XML files, each file type is merely given a different extension in order to assist the user in identifying the asset type, Figure 10.9. Like all XML files any of i1Profiler's asset files can be opened and viewed in a text editor or web browser.

The naming system for the X-Rite i1Profiler XML files are:

- pxf – Patch Sets
- txf – Test Charts
- mxf – Measurement Data
- lxf – Lighting Settings
- sxf – Profile Settings
- pxwf – Saved Workflows

The naming extension on any of the i1Profiler data files can be changed to .xml, and thereby the data contained within the files can be viewed, for example, when using the i1Pro2 in ambient mode the .lxf file can be opened and the spectral data from 380–730 nm can be extracted and plotted to compare the light booth response to perhaps, D50. An existing XML framework called XPath may be used to parse and extract data from i1Profiler's data files.

It is likely that we will see vendors using XML as their preferred file format for data files, as this increases interoperability and facilitates automation.


i1Profiler
Assets
Patch Sets
ECI 2002 CMYK random.pxf
i1Profiler 2033 Patches.pxf
IT8.7-3 CMYK visual.pxf
IT8.7-4 CMYK random.pxf
Test Charts
ECI 2002 CMYK random 1P i1iO.txf
IT8.7-4 CMYK random 1P i1iSis.txf
IT8.7-4 CMYK visual 1P i1iO.txf
Measurement Data
FOGRA50L.mxf
GRACoL 2006 Coated 1.mxf
SWOP 2006 Coated 3.mxf
SWOP 2006 Coated 5.mxf
Measure Reference
Lighting Settings
default.lxf
GTI Light Booth D50.lxf
GTI Light Booth D65.lxf
Profile Settings
Default Profile Settings.sxf
default.sxf
Offset 330-10-95-med+-100.sxf
ICC Profiles
Saved Workflows
sample-i1iO.pwxf
sample-i1iSis.pwxf
sample-i1Pro.pwxf
Patch Set
Chart 2033 Patches
Printer color setup
C
M
Y
K
Smart patch generator
Patchset ink limiting
Linearization

Number of generated patches: 2033

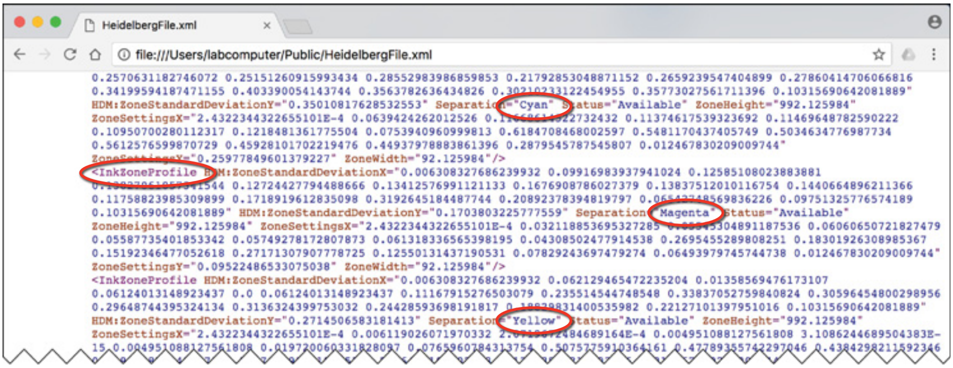
Scramble patches: ☐

Patch weighting (dark/light): 0

Total ink coverage: 400

Linearization file: None

Figure 10.9 The X-Rite i1Profiler assets are, despite the extension, all XML files.



```
0.2570631182746072 0.25151260915993434 0.28552983986859853 0.21792853048871152 0.2659239547404899 0.27860414706066816
0.34199594187471155 0.403390054143744 0.3563782636434826 0.30210233122454955 0.35773027561711396 0.10315690642081889"
HDM:ZoneStandardDeviationY="0.35010817628532553" Separation="Cyan" Status="Available" ZoneHeight="992.125984"
ZoneSettingsX="2.4322344322655101E-4 0.0639424262012526 0.1[illegible]22732432 0.11374617539323692 0.11469648782590222
0.10950700280112317 0.1218481361775504 0.0753940960999813 0.6184708468002597 0.5481170437405749 0.5034634776987734
0.5612576599870729 0.45928101702219476 0.44937978883861396 0.2879545787545807 0.012467830209009744"
ZoneSettingsY="0.25977849601379227" ZoneWidth="92.125984"/>
<InkZoneProfile HDM:ZoneStandardDeviationX="0.006308327686239932 0.09916983937941024 0.12585108023883881
0.[illegible]544 0.12724427794488666 0.13412576991121133 0.1676908786027379 0.13837512010116754 0.1440664896211366
0.11758823985309899 0.1718919612835098 0.3192645184487744 0.20892378394819797 0.06[illegible]569836226 0.09751325776574189
0.10315690642081889" HDM:ZoneStandardDeviationY="0.1703803225777559" Separation="Magenta" Status="Available"
ZoneHeight="992.125984" ZoneSettingsX="2.4322344322655101E-4 0.03211885369532728[illegible]304891187536 0.06060650721827479
0.05587735401853342 0.05749278172807873 0.0613183365653981 95 0.04308502477914538 0.2695455289808251 0.18301926308985367
0.15192346477052618 0.27171307907778725 0.12550131437190531 0.07829243697479274 0.06493979745744738 0.012467830209009744"
ZoneSettingsY="0.09522486533075038" ZoneWidth="92.125984"/>
<InkZoneProfile HDM:ZoneStandardDeviationX="0.006308327686239932 0.062129465472235204 0.01358569476173107
0.06124013148923437 0.0 0.06124013148923437 0.11167915276503079 0.235514544748548 0.33837052759840824 0.30596454800298956
0.29648744395324134 0.3136324399753032 0.24428593698191817 0.1[illegible]831400535982 0.22127101397951016 0.10315690642081889"
HDM:ZoneStandardDeviationY="0.2714506583181413" Separation="Yellow" Status="Available" ZoneHeight="992.125984"
ZoneSettingsX="2.4322344322655101E-4 0.006119026071970332 2.[illegible]484689164E-4 0.004951088127561808 3.1086244689504383E-
15 0.004951088127561808 0.019720060331828097 0.07659607843137254 0.5075775910364161 0.47789355742297046 0.4384298211592346
```

Figure 10.10 The numbers shown in this JDF XML file are ink key settings for an offset press, for each of the cyan, magenta, and yellow channels.

10.5.5 JDF

Color control on an offset press can be done via an XML vocabulary called JDF (Job Definition Format). The JDF schema is developed by an organization called CIP4 which has established an XML vocabulary for automation in the printing industry.

JDF can be used to encode information relating to the ink keys in offset printing, Figure 10.10. An offset press has ink zones and the ink keys must be adjusted to reflect the content of the job. Predictive ink key presets can be communicated from prepress to the press console to enable quicker make-ready on press. The instructions can be stored in an XML file that consists of elements and attributes created according to the CIP4 schema. In Figure 10.10 we see rows of numbers that relate to the 16 ink zones on the press and we see that there are instructions for each of the four-color separations.

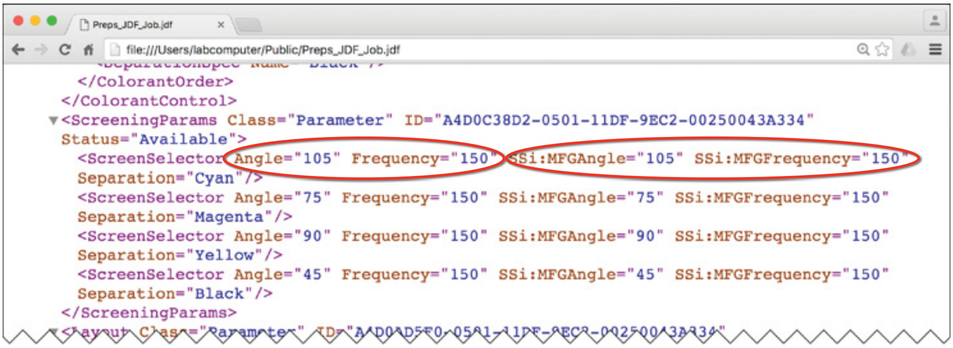
As there are no proprietary files, there is no need to conduct integrations where a user coerces the data to transfer between the prepress and press system from different manufacturers. Prepress data from Kodak or AGFA could go to a press console from Heidelberg or Komori. When job data is routed between systems via instructions in an XML file we benefit from a process that is non-proprietary, and it is efficient and error-free as it does not need human intervention to re-key the job information. This whole process allows us to achieve correct color on press, very quickly.

10.6 XML “not-best” Practices

Color management and prepress programs continue to adopt XML for data storage and exchange, however, not all programs follow best practices.

Consider Kodak Preps imposition software that creates page layouts for printing and proofing. The layout can be exported as an XML file in order that it can be consumed by an imagesetter or RIP or workflow system, Figure 10.11. This XML code snippet relates to the screening parameters for generation of a halftone separation.

The problem, is that attributes for “Angle” and “Frequency” are stored in a public attribute and again in a private attribute. Private tags are perfectly valid but should be kept to a minimum as their use reduces interoperability. Private tags, as indicated by

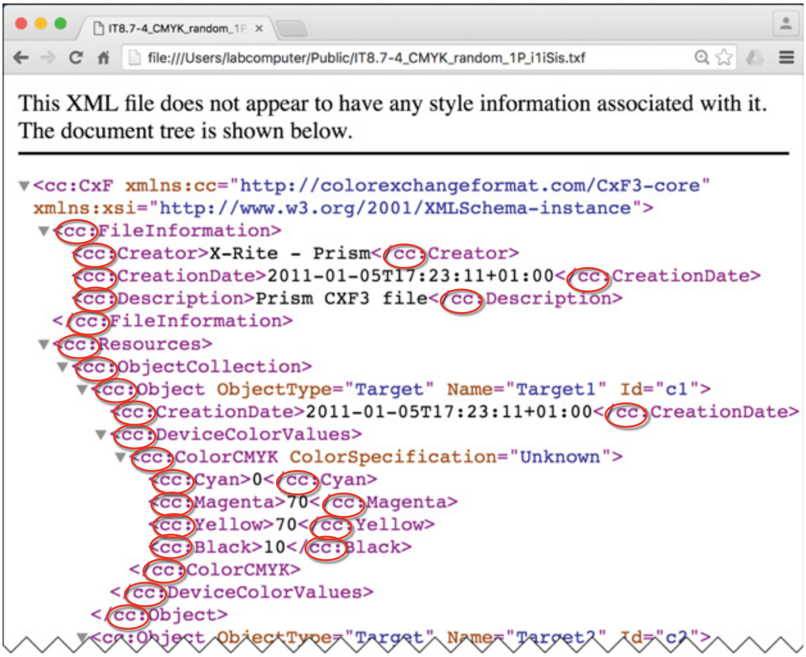

Preps_JDF_Job.jdf
file:///Users/labcomputer/Public/Preps_JDF_Job.jdf

```
    </ColorantOrder>
  </ColorantControl>
▼<ScreeningParams Class="Parameter" ID="A4D0C38D2-0501-11DF-9EC2-00250043A334"
  Status="Available">
    <ScreenSelector Angle="105" Frequency="150" SSi:MFGAngle="105" SSi:MFGFrequency="150"
    Separation="Cyan"/>
    <ScreenSelector Angle="75" Frequency="150" SSi:MFGAngle="75" SSi:MFGFrequency="150"
    Separation="Magenta"/>
    <ScreenSelector Angle="90" Frequency="150" SSi:MFGAngle="90" SSi:MFGFrequency="150"
    Separation="Yellow"/>
    <ScreenSelector Angle="45" Frequency="150" SSi:MFGAngle="45" SSi:MFGFrequency="150"
    Separation="Black"/>
  </ScreeningParams>
```

Figure 10.11 Kodak Preps duplicates Angle and Frequency in public and private SSi XML attributes – a potentially dangerous situation.

the prefix SSi, are perfectly valid but should only be used in situations where there is no public tag available. Screen angle and screen frequency are readily available as shown in Figure 10.11, thus it is not appropriate to use a private tag when an equivalent public tag exists.

Another example of poor XML implementation is evident in X-Rite's i1Profiler data files, Figure 10.12. The prefix "cc" is repeated in front of each open and close part of the element name. There is no need to repeat the "cc" prefix throughout the file. If a


IT8.7-4_CMYK_random_1P
file:///Users/labcomputer/Public/IT8.7-4_CMYK_random_1P_i1iSis.txf

This XML file does not appear to have any style information associated with it. The document tree is shown below.

```
▼<cc:CxF xmlns:cc="http://colorexchangeformat.com/CxF3-core"
 xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  ▼<cc:FileInformation>
     <cc:Creator>X-Rite - Prism</cc:Creator>
     <cc:CreationDate>2011-01-05T17:23:11+01:00</cc:CreationDate>
     <cc:Description>Prism CXF3 file</cc:Description>
   </cc:FileInformation>
  ▼<cc:Resources>
   ▼<cc:ObjectCollection>
    ▼<cc:Object ObjectType="Target" Name="Target1" Id="c1">
       <cc:CreationDate>2011-01-05T17:23:11+01:00</cc:CreationDate>
      ▼<cc:DeviceColorValues>
       ▼<cc:ColorCMYK ColorSpecification="Unknown">
          <cc:Cyan>0</cc:Cyan>
          <cc:Magenta>70</cc:Magenta>
          <cc:Yellow>70</cc:Yellow>
          <cc:Black>10</cc:Black>
        </cc:ColorCMYK>
      </cc:DeviceColorValues>
    </cc:Object>
```

Figure 10.12 X-Rite i1Profiler XML asset files repeat the "cc" prefix unnecessarily, creating a file that is difficult to read.

schema is declared in the root element, then all subsequent nested elements inherit this instruction and there is no need to specify "cc" repeatedly. i1Profiler is unnecessarily making the code more complex to read, which is definitely not one of the XML design principles.

In the past code was hidden and software developers could do what they like behind closed doors. With XML, data structures are now visible and are just one click away from examination by the user. During these early days of XML implementation it is normal to see some teething problems. As color management software companies gain experience with XML it is expected that there would be more precise and efficient use of XML.

10.7 Summary

This chapter provided an introduction and overview to XML technology including a description of the main components of XML, i.e. the declaration, elements, attributes, and schemas. XML is easy to understand and can be viewed using a web browser or text editor. It was shown that XML is a type of markup language, sharing many similarities with HTML.

There are many different XML vocabularies where a technology area or industry group has agreed to use only specific XML element names and attributes. The creation of standard vocabularies has greatly increased interoperability and efficient information interchange between applications and systems.

The benefits of XML-based automation were shown using a number of color management examples. An easy way to view and edit the contents of a binary-encoded ICC profile is via translation into XML, as used in iccMAX. The Windows Color System (WCS) is entirely XML based. The Color Exchange Format (CxF) for spot colors has adopted XML encoding, and example XML files from X-Rite i1Profiler were examined. XML in print automation with JDF was described

The simplicity of XML contributes greatly to its widespread adoption making it a pervasive technology today. It was demonstrated that many color management systems rely on XML, so it is therefore useful for everybody in a company to have at least a basic understanding of what XML is, and what it can do.

Future color management systems will also be XML based, including for example Idealliance's Print Quality eXchange (PXF) and Spot Color Halftone Metric Optimization (SCHMO) that are currently in development. XML is widely used today and its use is set to grow even more in the future.

This chapter provided an introduction and overview to XML technology for non-technical audiences. In general, XML should be hidden from the end user and work invisibly behind the scenes, however, there are many instances we may need to examine an XML file, for example in analysis of spot color spectral data or to extract instrument measurement data from an XML file.

11

Color Management in Photoshop

Objectives

- Explain Photoshop's menus and dialogs for color management.
- Describe the concept of Photoshop's Working Space.
- Describe Photoshop's ICC color management implementation.
- Demonstrate a complete, color managed workflow including printing and proofing.

11.1 Introduction

Many users will have first come into contact with color management through Adobe applications, in particular Adobe Photoshop. Photoshop was one of the first applications to offer color management to the general user. Photoshop remains a primary application for opening and editing images whether from digital cameras or for press-ready workflows. Photoshop exploits all of the functionality of an ICC workflow, including color conversions, color corrections, soft proof, press proof and embedding profiles in an image. Photoshop can be used for an exclusively RGB workflow yet provide full preview of the CMYK results. Photoshop can do nearly any color management operation – you just need to know how!

Today every image must have an associated ICC profile: all workflow software, RIPs, and operating systems (macOS and Windows) insist on a profile. It is reassuring therefore to see that, in Photoshop too, we must have a profile from the very first ***File>Open...*** dialog.

This chapter has a number of sections describing the general principles of color management in Photoshop. We look at how Photoshop evolved and how color management became integral to it. We then look at the simple operational rules Photoshop uses, such as, every image must have a profile, and all conversions require at least two profiles, a source and a destination profile. Next we deal with implementing color management in Photoshop, and the concept of a Working Space. We then describe Photoshop menus and operations such as ***Color Settings***, ***Assign Profile***, and ***Convert to Profile***. Next we consider a number of Photoshop's print options including creating a hardcopy press

Understanding Color Management, Second Edition. Abhay Sharma.
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proof. Photoshop is the best program to use for real-world color management, so in the final part of the chapter we demonstrate how to set up a color-managed workflow. The example workflow brings together concepts from many parts of this book.

Through an evolutionary process Adobe has arrived at a stable color management strategy that is correct, works well, is widely accepted, and can be synced across the Adobe suite of applications. Even if your job does not directly involve using Photoshop, every color user should know their way round this program as it is used as a benchmark for color management. Within color management circles, Photoshop provides the "gold standard," and any debate is often decided with reference to the results achieved in Adobe Photoshop.

All recent versions of Photoshop CS and Photoshop CC work in a very similar manner with essentially the same basic color architecture. Photoshop continues to be updated, and with the addition of some last missing pieces (Multichannel, Device Link and Abstract profiles) we are finally at a very complete color managed program. The screen shots used throughout this chapter were made with Photoshop CC 2017 on macOS, but the explanations are very similar, if not identical for, Windows users and earlier versions of Photoshop CS and Photoshop CC.

11.2 Photoshop Through the Ages

It is interesting to trace some of the steps and pitfalls that Photoshop has encountered on its way to becoming the premier image editing and color management program.

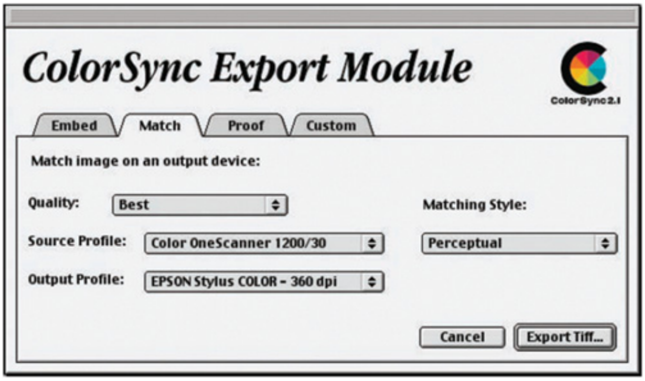
Photoshop was introduced 25 years ago and since then has revolutionized the world of color management. Without Photoshop, color management was sidelined to expensive, niche markets, which is exactly the situation ICC-color management had desired to move away from.

In 1990, two brothers, Thomas and John Knoll, under license to Adobe, launched version 1 of Photoshop. It was not until later that Adobe fully owned the Photoshop code and product. Photoshop was by all accounts a runaway success, and by the mid-1990s was at version 3. At about the same time, the Apple ColorSync Consortium was beginning to gather momentum.

Within the graphic arts industry, color management was not widely adopted as an essential part of the workflow, but there is evidence that Adobe and Apple recognized the importance of each other's inventions. Whereas color management did not become a core part of Photoshop until much later, from version 3 onward ColorSync's color management module was available as an external plug-in to Photoshop, Figure 11.1.

After color management became integrated within Photoshop, there remained for many years a link between Photoshop dialogs and what a user may have chosen in external macOS ColorSync settings, Figure 11.2. This was a reassuring feature of Photoshop. Whenever you selected this option it meant that Photoshop would use the settings that had been stipulated at the OS level in a relevant ColorSync dialog. This linking is largely redundant today, and has been phased out.

By the late 1990s, color management had become a buzzword, and many users were keen to explore its potential. Unfortunately, color management turned out to be quite tricky to implement. In 1998, Adobe launched Photoshop 5, which added to the confusion. Photoshop 5 managed color in a manner dramatically different from earlier



Match image on an output device:

Quality: Best

Source Profile: Color OneScanner 1200/30

Output Profile: EPSON Stylus COLOR - 360 dpi

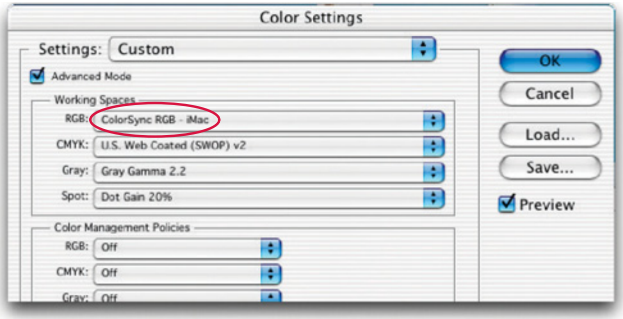
Matching Style: Perceptual

Figure 11.1 Many years ago, in Photoshop 3, color management was not even part of Photoshop and required an external ColorSync plug-in.

versions of the software and forced images into the Working Space, a new concept at that time. The changes were not well documented by the vendor and were not well understood by users. The system that Photoshop 5 employed could easily make unwanted and unnecessary changes to the color of images, and often it did. Adobe tried to smooth over some of the problems by providing a color management wizard. However, the damage was done, and many small-and medium-sized agencies suffered disruption that led to some negative feedback for color management.

Users had to wait until the end of 2000 for Photoshop 6, which would end their color management woes. Photoshop 6 was fantastic in terms of color management; it carried on and improved the useful parts of the color management strategy of earlier versions of Photoshop, but it removed the bad "forced" workflows relating to the Working Space.

Fundamentally, in terms of color management, little has changed since Photoshop of the early 2000's. Despite many more versions and name changes, the program retains a correct implementation of an open color management system, and color management is correctly implemented in all versions of Photoshop CS to Photoshop CC. One of the last



Settings: Custom

☑ Advanced Mode

Working Spaces

RGB: ColorSync RGB - iMac

CMYK: U.S. Web Coated (SWOP) v2

Gray: Gray Gamma 2.2

Spot: Dot Gain 20%

Color Management Policies

RGB: Off

CMYK: Off

Gray: Off

Figure 11.2 ColorSync and Photoshop have always been closely aligned, a user was able to pull in the ColorSync settings into Photoshop 7.

ICC profile types to enjoy support within Photoshop are Multichannel, Device Link, and Abstract color profiles. These last missing features have finally been introduced enabling all ICC operations to be realized in the program. Some packaging users are still patiently waiting for proper rendition of multichannel spot color tints.

Through an evolutionary process Adobe has arrived at a stable color management architecture that works well, is widely accepted, and continues to have millions of users across the world.

11.3 Photoshop's Color Management Rules

This section provides an overview to Photoshop's color management philosophy. Photoshop's implementation of color management is in accordance with an "ICC workflow", and implements this very well.

Figure 11.3 shows a color management workflow that is much the same as we have described in earlier chapters. Photoshop introduces a small addition to the workflow diagram called the Working Space.

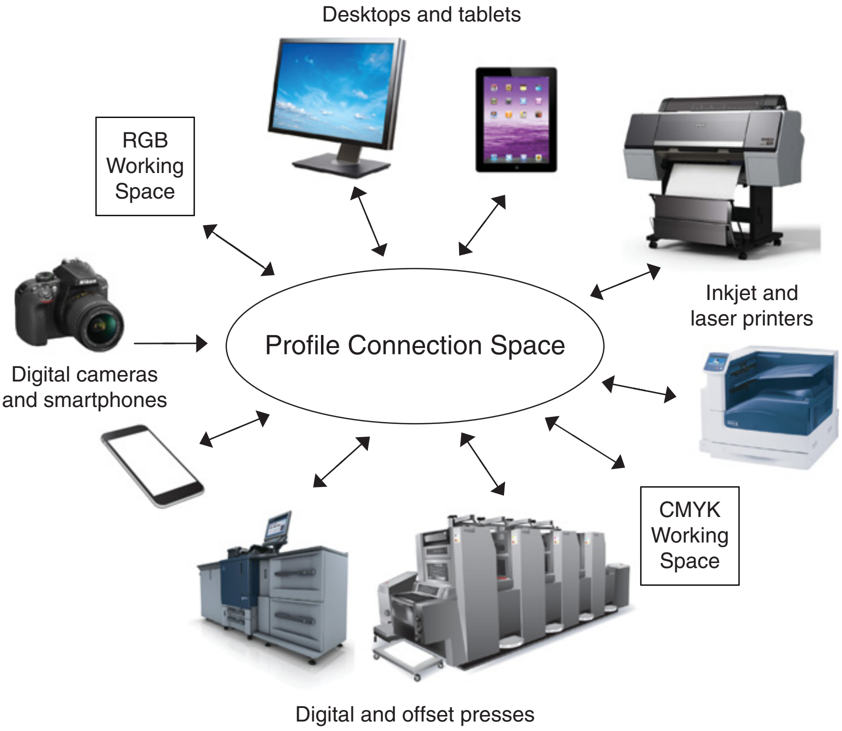

Desktops and tablets
RGB Working Space
Inkjet and laser printers
Profile Connection Space
Digital cameras and smartphones
CMYK Working Space
Digital and offset presses

Figure 11.3 Photoshop has introduced the concept of a Working Space. It is easy to visualize the Working Space as another "device" in a color managed system. *Source:* Epson®, Xerox®, Nikon Corporation. Image from Konica Minolta Business Solutions, reproduced with permission. Images of iPad and LCD panel licensed by Ingram Image.

Color management operations in Photoshop can be summarized by three basic rules.

- Rule 1: Every image must have a profile.
- Rule 2: All color conversion operations in Photoshop require at least two profiles – a source and a destination profile.
- Rule 3: In Photoshop, it is possible to do color conversions in simulation or for real.

Let us review these rules in relation to Figure 11.3.

11.3.1 Rule 1: Image + Profile

We have seen in earlier chapters that each device has its own characteristics, and therefore its own profile. Thus every device (or more accurately, an image from that device) must have a profile. So Rule 1 in Photoshop (and color management in general) is that every image must have a profile. The profile connects the device to the central connection space and allows us to bring the image into a color-managed workflow, allowing the RGB/CMYK values to be correctly interpreted in terms of color.

When Photoshop opens an image it checks to see if the image has an embedded profile. If the image does not have an embedded profile the program helps you assign one. Every image must have a profile, and this includes processed images. Thus after an image has been processed – for example, from RGB to CMYK – a profile is embedded in the image. The profile in this instance will be the CMYK printer profile.

In Photoshop jargon, an image is "tagged" with a profile. If there is no profile associated with an image, the image is "untagged." Photoshop has a special mechanism to deal with untagged images.

11.3.2 Rule 2: Profile – Connection Space – Profile

Rule 2 in Photoshop (and color management) is that every color conversion needs two profiles. An image is always converted from one color space to another. Thus we may say "profile – connection space – profile." You need to have a source profile (which tells you where the image is coming from) and a destination profile (which tells you where the image is going to). In Photoshop's color conversion dialogs you are always asked for two profiles: a source profile and a destination profile. A typical scenario would be to convert from RGB to CMYK using a camera source profile and a printer destination profile.

"Source" and "destination" refer simply to the sequence in which a profile is used. Whichever profile is first, is called the source, and the second profile in the sequence is the destination. It is important to realize that a profile can be a source or destination profile, based simply on the order in which it is used. If we are bringing a CMYK image back into the workflow and wish, for example to process CMYK data to another type of printer system, in this instance a GRACoL profile, normally a destination, could be used as a source profile.

11.3.3 Rule 3: Real vs. Simulated Conversions

Rule 3 says that we should seek to avoid color conversions. In Photoshop, and color management in general, the emphasis is on avoiding unnecessary color conversions and delaying color conversions until late in the workflow. With every conversion, for example from RGB to CMYK, there is the potential for the irreversible loss of some image colors due to gamut limitations, and there is always some small loss in quality due to inaccuracies in the color conversion and interpolation math.

Photoshop can of course do a real conversion of image data from RGB to CMYK, which changes the pixel values in the image. But Photoshop has a better way of working. The program can take an image and simulate the effect of the source and destination profiles, and thus provide a prediction of the outcome, without causing any real change in the underlying image's pixel values. Thus Photoshop offers a choice between doing *real conversions* and a *simulation* of the conversion. Nearly every process in Photoshop can be done in real and also in simulation. It is useful to be able to recognize which dialogs represent a permanent change to the image and which are simulated changes. Obviously, where possible, the simulated route should be used.

11.4 Photoshop's Working Space

Before we begin to explore Photoshop's menus and dialogs, we need to understand the concept of the Working Space. This is a concept unique to Photoshop (and other Adobe applications), but it can be conceptualized within an ICC workflow. Photoshop allows any valid ICC profile to be selected as the Working Space, thus we stipulate an RGB, CMYK, Gray and Spot Working Space.

The Working Space (and its profile) can be thought of as simply another device in the chain, as indicated in Figure 11.3. The Working Space is connected to the profile connection space using a profile just like any other device. The Working Space profile is an ICC profile and can be a standard profile, such as sRGB, or a device profile, such as a digital camera profile. In general the Working Space profile should be a well-made and reputable profile, so in general we would tend to avoid using device profiles from your local system.

The Working Space/Working Space profile is used in a number of Photoshop operations. Newly created images, for example, will automatically assume the Working Space profile. Yet another use of the Working Space, arises when images have no profile at all. In the case of images with no associated profile, the Working Space profile is used.

You may want to convert your images into a Working Space if you are working in a group and want all members of a team to be able to easily exchange images. Or you may want to archive the images in a standard format for easy retrieval at a later date. In such cases, using a standard Working Space may make life easier.

Some practitioners argue that a scanner/digital camera space is not perceptually uniform, and editing an image in these spaces is not optimum. It is argued that a Working Space (such as sRGB, Adobe RGB) is a better constructed color space, is perceptually more uniform and therefore is a much better space in which to edit and work with images.

A good recommendation is to retain the image in its source space and to convert the image into one of the Working Spaces only when there is a compelling reason to do so. This lingering fascination with the Working Space is perhaps a throwback to when color management first started in Photoshop and the Working Space was a central feature of the color management pathway.

11.5 Menus in Photoshop

Now that we have established a foundation for color management in Photoshop we are ready to look at the details of specific menus and dialogs. In Photoshop, color management is controlled and implemented in a few different areas. These dialogs are sprinkled throughout the interface, as shown in Figure 11.4. We can consider the color management menus in Photoshop to be as follows:

- ***File>Open...*** – When you open an image, you may see the ***Missing Profile*** or ***Embedded Profile Mismatch*** dialogs.
- ***File>Print...*** – To print an image to an inkjet printer or to proof a commercial web press on an inkjet proofer.
- ***Edit>Color Settings...*** – This sets the general color management settings for the program.
- ***Edit>Assign Profile...*** – This menu is used to change the source profile associated with an image.
- ***Edit>Convert to Profile...*** – To convert an image from a source to any destination colorspace.

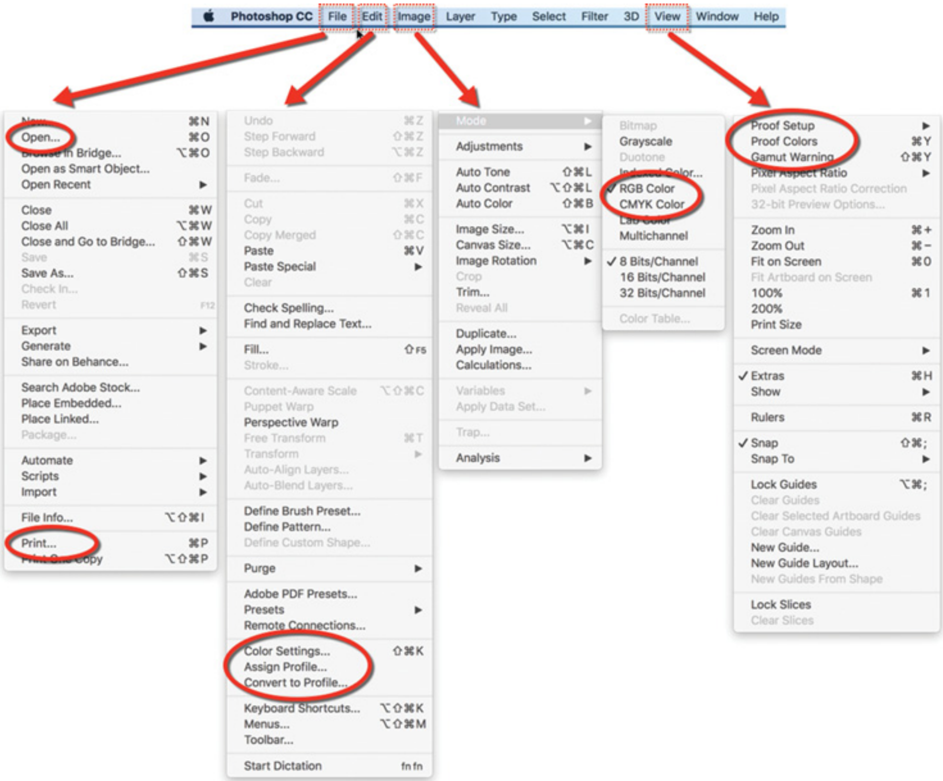

Photoshop CC
File
Edit
Image
Layer
Type
Select
Filter
3D
View
Window
Help
Open...
in Bridge...
Open as Smart Object...
Open Recent
Close
Close All
Close and Go to Bridge...
Save
Save As...
Check In...
Revert
Export
Generate
Share on Behance...
Search Adobe Stock...
Place Embedded...
Place Linked...
Package...
Automate
Scripts
Import
File Info...
Print...
Copy
Undo
Step Forward
Step Backward
Fade...
Cut
Copy
Copy Merged
Paste
Paste Special
Clear
Check Spelling...
Find and Replace Text...
Fill...
Stroke...
Content-Aware Scale
Puppet Warp
Perspective Warp
Free Transform
Transform
Auto-Align Layers...
Auto-Blend Layers...
Define Brush Preset...
Define Pattern...
Define Custom Shape...
Purge
Adobe PDF Presets...
Presets
Remote Connections...
Color Settings...
Assign Profile...
Convert to Profile...
Keyboard Shortcuts...
Menus...
Toolbar...
Start Dictation
Mode
Adjustments
Auto Tone
Auto Contrast
Auto Color
Image Size...
Canvas Size...
Image Rotation
Crop
Trim...
Reveal All
Duplicate...
Apply Image...
Calculations...
Variables
Apply Data Set...
Trap...
Analysis
Bitmap
Grayscale
Duotone
Color...
✓ RGB Color
CMYK Color
Multichannel
✓ 8 Bits/Channel
16 Bits/Channel
32 Bits/Channel
Color Table...
Proof Setup
Proof Colors
Gamut Warning
Pixel Aspect Ratio
Pixel Aspect Ratio Correction
32-bit Preview Options...
Zoom In
Zoom Out
Fit on Screen
Fit Artboard on Screen
100%
200%
Print Size
Screen Mode
✓ Extras
Show
Rulers
✓ Snap
Snap To
Lock Guides
Clear Guides
Clear Selected Artboard Guides
Clear Canvas Guides
New Guide...
New Guide Layout...
New Guides From Shape
Lock Slices
Clear Slices

Figure 11.4 Adobe Photoshop provides a wide range of color management operations, spread across a number of different drop-down menus.

- ***Image>Mode*** – Converting from RGB to CMYK – this is a quick color mode change, but is not recommended.
- ***View> Proof Setup, Proof Colors, Gamut Warning*** – A very powerful part of Photoshop that allows us to preview an image before it is printed.

11.5.1 Opening an Image

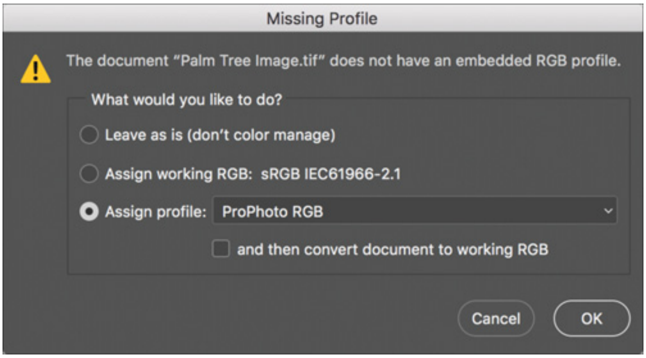
Let's look at how we can open an image in Photoshop. Remember that color management only works if we have a profile for our image. If an image has an embedded profile, and we trust the appropriateness of that profile, then we are ready to open and start using the image in a color-managed way. If the image has no profile then Photoshop gives us some options. When you open an image without an embedded profile the ***Missing Profile*** dialog may appear, as shown in Figure 11.5.

You have three choices. You can ***Leave as is***. You can choose to continue without any profile, which means that you have decided not to employ a color managed process. ***Leave as is*** will open the image without performing any conversions. You may use this option if you are interested in the pixel values of an image – for example, in a test target.

Generally, however, you will want to work within a color managed environment. In this case, ***Assign working RGB***, assigns the current Working Space profile to the image.

The final option is to ***Assign profile*** from the available profiles you have in your profiles folder. Suppose, for example, you have an image captured with a digital camera that did not embed a profile. If you know the appropriate profile to use, now is a good time to assign that profile to the image.

After assigning a profile, the ***Missing Profile*** dialog offers the option ***and then convert document to working RGB***. If you consider Figure 11.3, it is easy to see what Photoshop is offering to do. Photoshop is offering to assign an input profile to your image and then process the image into the Working Space. Thus the image data will now be in the Working Space, and the profile associated with the image will be the Working Space profile. Note that information about the original profile that was embedded in the image will no longer be available.



Missing Profile

The document "Palm Tree Image.tif" does not have an embedded RGB profile.

What would you like to do?

○ Leave as is (don't color manage)

○ Assign working RGB: sRGB IEC61966-2.1

● Assign profile: ProPhoto RGB

☐ and then convert document to working RGB

Figure 11.5 Every image must have a profile, if a profile is missing, Photoshop offers a ***Missing Profile*** dialog.

Many years ago in Photoshop it was obligatory to convert the image into the Working Space. However, there is no longer any need to do so. The Working Space may have a restricted gamut, and thus, unless you have a reason to do so, it is best not to convert into it.

When you open an image there is another dialog that may appear called ***Embedded Profile Mismatch***. You get this dialog if you open an image and the embedded profile in the image does not match the Working Space profile. There is similarity between the options in ***Missing Profile*** and ***Embedded Profile Mismatch***.

11.5.2 Image Status

Once an image is opened, Photoshop has a number of ways to help us keep track of the image's profile and color management status. Cryptic * and # symbols are used next to the file name, these are very significant, yet not well documented. Here we explain the meaning of these symbols.

The profile associated with an image is shown in the lower left of the image window, Figure 11.6. This part of the window normally shows the file size but can be changed to show the profile name.

Whenever an image has a profile that is not the same as the Working Space profile, Photoshop gives us a gentle reminder by placing an asterisk (*) next to the file name in the title bar, Figure 11.6. Today there is no compulsion to use the Working Space, so this warning is simply a courtesy. When working in Photoshop, if you have made some edits

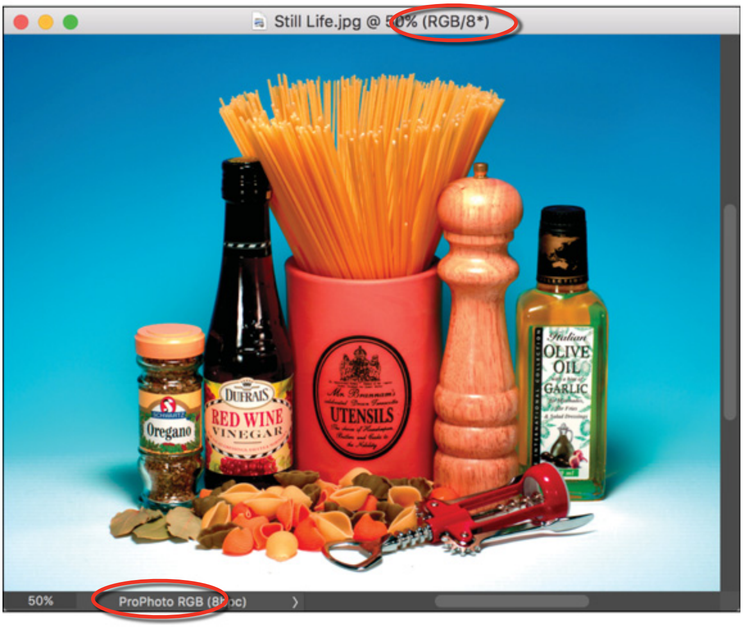
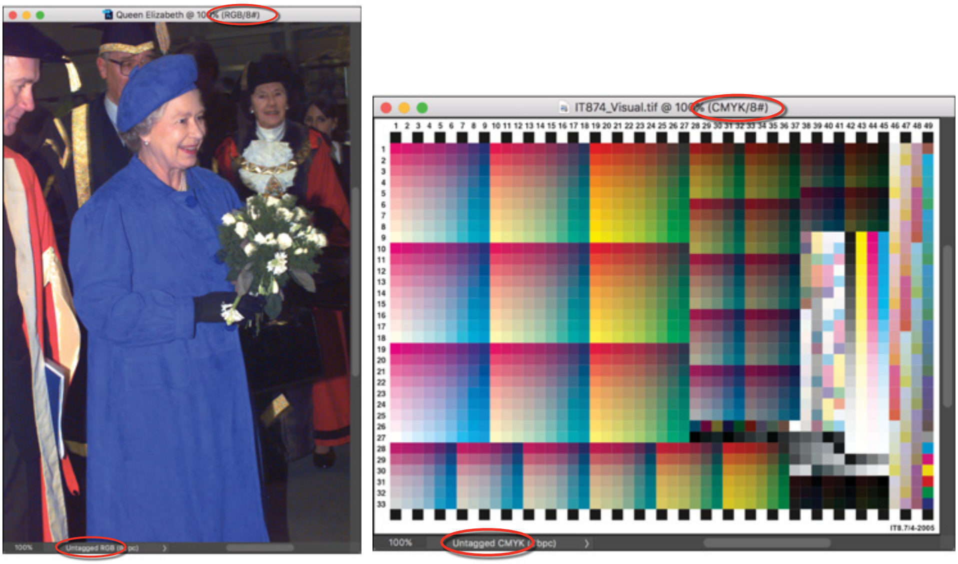


Figure 11.6 An asterisk (*) in Photoshop's title bar indicates that the image's profile is not the same as the Working Space.


Queen Elizabeth @ 100% (RGB/8#)
100%
Untagged RGB (8 bpc)
IT874_Visual.tif @ 100% (CMYK/8#)
100%
Untagged CMYK (8 bpc)
IT8.7/4-2005

(a) (b)

Figure 11.7 Photoshop uses the "hash" or "number sign" symbol (#) in the title bar to indicate that the Working Space profile is being used to display an untagged image.

and have not saved your changes, an asterisk is added to the file name, so you can get a double asterisk in some situations, such as (RGB/8*)*.

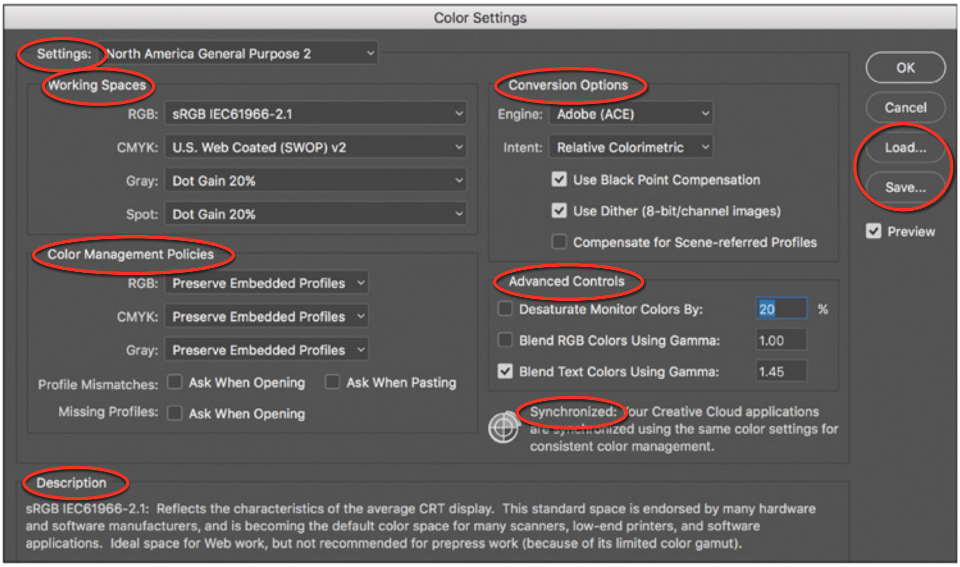
One of the options when opening an image is to ***Leave as is (don't color manage)***, i.e. use no profile for the image. We would use this option in situations where we are interested in the pixel values in an image or for example when opening a test chart. If there is no profile associated with an image the entry in the bottom left of the image window reads as Untagged RGB or Untagged CMYK, Figure 11.7.

When an image is untagged, the title bar of the window will show the "hash" or "number sign" symbol (#), beside the file name. The (#) symbol is Photoshop's way of pointing out that it must have a profile for many operations and, as the user has not assigned a profile, the program is going to use the Working Space profile where needed.

11.5.3 Color Settings

The ***Color Settings*** dialog, is a major color management dialog, found in ***Edit>Color Settings...***, Figure 11.8. The ***Color Settings*** dialog is used to establish the general color operating environment for the program.

- ***Settings*** – At the top of the dialog is a Settings option that provides a range of suggested standard configurations. If you choose different Settings this changes the rest of the dialog according to predetermined configurations. The ***Settings*** configuration can be saved and shared, allowing different users in the same company to easily align their color configuration, or to share the settings with an external customer or client. A default Settings is North America General Purpose 2. This setting uses sRGB, and a



Settings: North America General Purpose 2

RGB: sRGB IEC61966-2.1
CMYK: U.S. Web Coated (SWOP) v2
Gray: Dot Gain 20%
Spot: Dot Gain 20%

RGB: Preserve Embedded Profiles
CMYK: Preserve Embedded Profiles
Gray: Preserve Embedded Profiles
Profile Mismatches: ☐ Ask When Opening ☐ Ask When Pasting
Missing Profiles: ☐ Ask When Opening

Engine: Adobe (ACE)
Intent: Relative Colorimetric
☑ Use Black Point Compensation
☑ Use Dither (8-bit/channel images)
☐ Compensate for Scene-referred Profiles

☐ Desaturate Monitor Colors By: 20 %
☐ Blend RGB Colors Using Gamma: 1.00
☑ Blend Text Colors Using Gamma: 1.45

Synchronized: Your Creative Cloud applications are synchronized using the same color settings for consistent color management.

sRGB IEC61966-2.1: Reflects the characteristics of the average CRT display. This standard space is endorsed by many hardware and software manufacturers, and is becoming the default color space for many scanners, low-end printers, and software applications. Ideal space for Web work, but not recommended for prepress work (because of its limited color gamut).

Figure 11.8 Photoshop uses the Color Settings dialog to establish the general color operating procedures for the program.

legacy CMYK profile – US Web Coated (SWOP) v2. Both of these are no longer representative of the color abilities of modern systems – they are very old and both have relatively small gamuts. This undesirable settings choice is retained in the program due to the widespread adopted user base.

- ***Working Spaces*** – An important part of the dialog is the section for Working Spaces. The Working Space RGB profile can be set to sRGB, ColorMatch RGB, Apple RGB, or any other valid RGB profile. Photoshop only shows you allowed profiles, thus the RGB Working Space only reveals a list of RGB profiles, and CMYK Working Space, CMYK profiles, etc. The choice of Working Space is relevant, we have seen for example, how Photoshop uses it to deal with an image that doesn't have a profile.
- ***Color Management Policies*** – This section of the dialog establishes what you would like to do when opening an image. When you first begin to work with Photoshop, it is probably a good idea to select ***Profile Mismatches: Ask When Opening***, so you are presented options from which to make an informed choice. Each image in Photoshop can have a different profile, if you ***Ask When Pasting*** you will encounter a warning when pasting between images that have different profiles. You would normally Convert (preserve color appearance) when you get this warning.
- ***Description*** – There is a help function for all the elements of this dialog. If you hover your cursor over any of the dialog areas, very useful explanations and notes are displayed here.
- ***Conversion Options*** – This part of the dialog allows you to select a particular color engine and rendering intent for color conversions. Adobe Color Engine (ACE) refers to the Adobe Color Management Module (CMM). A user seeking to obtain identical results on both Apple and PC platforms, or across different products, may seek

to choose the same CMM in all applications. The rendering intent in the ***Conversion Options*** does not control the rendering intent for image conversions – they are stipulated in application dialogs. The rendering intent here in the Conversion Options controls the calculation for the Info palette in Photoshop, something that is relevant for the advanced-level, troubleshooting.

- ***Advanced Controls*** – These controls are used to bring the monitor closer to the printed output. ***Advanced Controls*** can be used for "rough and ready" soft proofing.
- ***Synchronized*** and ***Load.../Save...*** – Before we leave the ***Color Settings*** dialog, it is useful to notice the ***Synchronized*** and ***Load/Save*** buttons. Photoshop provides compatibility with its other applications by allowing the color settings to be saved and used in other applications, such as InDesign and Illustrator. The color settings are saved as a file with a .csf extension and can be mailed to another user, or Adobe Bridge can be used to synchronize the Color Settings to ensure that color is managed consistently between Adobe applications. Adobe applications can also detect when an application in a synchronized set has been changed.

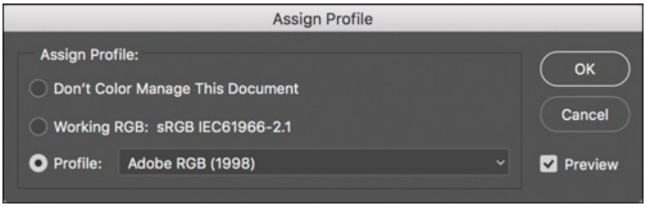
11.5.4 Assign Profile

Edit>Assign Profile and ***Edit>Convert to Profile*** are two side-by-side menu items in Photoshop. An easy way to remember the difference between ***Assign Profile*** and ***Convert to Profile*** is that ***Assign Profile*** relates to the source or input profile, while ***Convert to Profile*** generally relates to the destination or output profile.

Consider first, ***Edit>Assign Profile***, Figure 11.9. If after you have opened or created an image and you change your mind about its profile then you can use ***Edit>Assign Profile*** to change it.

Or, if you have an image without a profile – an untagged image – then ***Assign Profile*** can be used to assign one. Assigning a profile can be done visually, different profiles can be selected in turn and the user can view the displayed colors and chose a realistic or desired look. In this process, don't necessarily choose the largest gamut profile, as choosing to assign a profile based on a profile with the largest gamut can sometimes cause image colors to "glow," Figure 11.10.

Assign Profile does not change the RGB pixel values in an image, it only changes the appearance. After a profile has been assigned to an image, it continues to live and travel with the image through Photoshop's other dialogs, providing information on how the image's pixel values should be interpreted in terms of color.



Assign Profile:

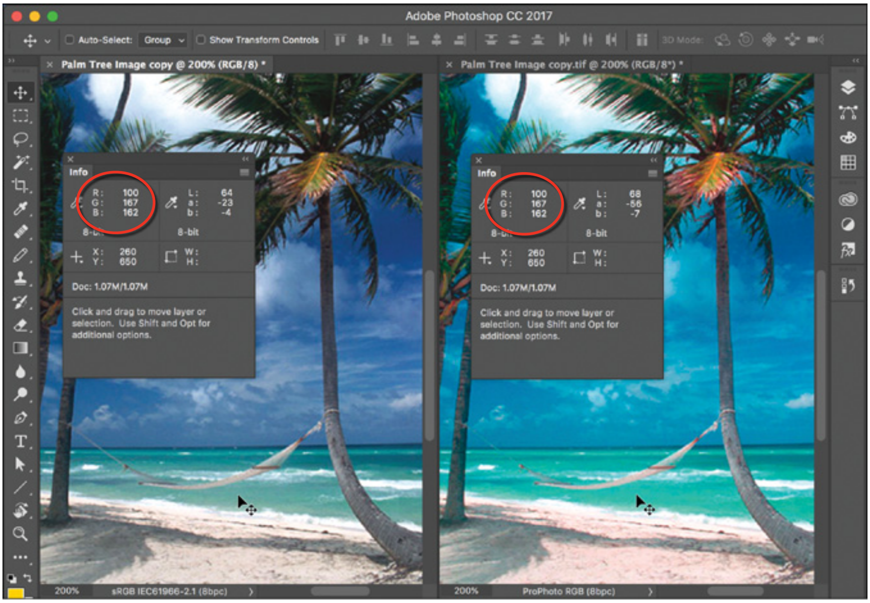
○ Don't Color Manage This Document

○ Working RGB: sRGB IEC61966-2.1

● Profile: Adobe RGB (1998)

☑ Preview

Figure 11.9 The ***Assign Profile*** dialog can be used to assign, or re-assign, a source or input profile to an image.



Info

R: 100
G: 167
B: 162
L: 64
a: -23
b: -4
8-bit
X: 260
Y: 650
W:
H:
Doc: 1.07M/1.07M

Click and drag to move layer or selection. Use Shift and Opt for additional options.

Info

R: 100
G: 167
B: 162
L: 68
a: -56
b: -7
8-bit
X: 260
Y: 650
W:
H:
Doc: 1.07M/1.07M

Click and drag to move layer or selection. Use Shift and Opt for additional options.

Figure 11.10 Assigning a profile to an image does not change the pixel values in the image, but the appearance of an image can change, notice the "neon" colors on the right.

11.5.5 Convert to Profile

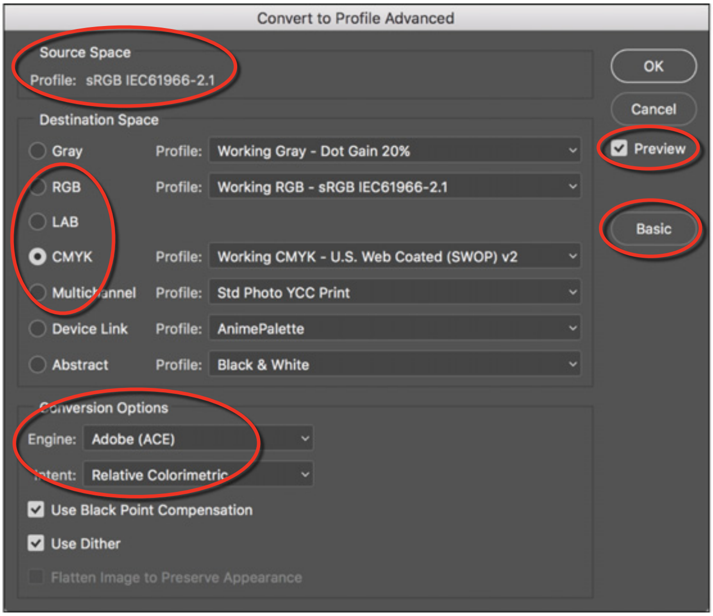
The ***Convert to Profile*** dialog does convert and alter pixels values. It is used, for example, to process an image for output, Figure 11.11. Image pixel values are processed from source to destination, perhaps from RGB to CMYK and then the image is tagged with the selected CMYK output profile. There is a Basic and Advanced version of this menu. The ***Convert to Profile*** process involves irreversible changes to the image, so if you are not sure you want to convert an image you are better off using a simulation and not a real conversion process. Let us summarize the dialog options and then consider how and when ***Convert to Profile*** should be used.

Source Space. The existing source profile for the image under consideration is shown at the top of the dialog.

Destination Space. You can convert an image into any other color space. RGB to CMYK conversions are possible as well as RGB to RGB and CMYK to CMYK, etc.

The ***Convert to Profile*** dialog can be used to process images to Multichannel profiles, perhaps from RGB to CMYK+OGV (Orange, Green, Violet), and a Device Link profile can be used to convert from one CMYK colorspace to a different CMYK, perhaps to redirect press output to a different print device. Abstract profiles can be used to apply a preferred color edit. By storing a color edit in a profile instead of using an adjustment layer, this allows for non-destructive adjustments and proofing.

Conversion Options. It is possible to specify the CMM and the rendering intent to be used during the conversion. ***Black Point Compensation*** is similar in principle to the relative and absolute colorimetric intents as described in Chapter 8. ***Black Point Compensation*** will only make a difference if there is a big difference in black level between



Convert to Profile Advanced

Source Space

Profile: sRGB IEC61966-2.1

Destination Space

○ Gray Profile: Working Gray - Dot Gain 20%

○ RGB Profile: Working RGB - sRGB IEC61966-2.1

○ LAB

● CMYK Profile: Working CMYK - U.S. Web Coated (SWOP) v2

○ Multichannel Profile: Std Photo YCC Print

○ Device Link Profile: AnimePalette

○ Abstract Profile: Black & White

Conversion Options

Engine: Adobe (ACE)

Intent: Relative Colorimetric

☑ Use Black Point Compensation

☑ Use Dither

☐ Flatten Image to Preserve Appearance

☑ Preview

Figure 11.11 The ***Convert to Profile*** dialog governs color conversion operations and now includes Device Link and Abstract profiles.

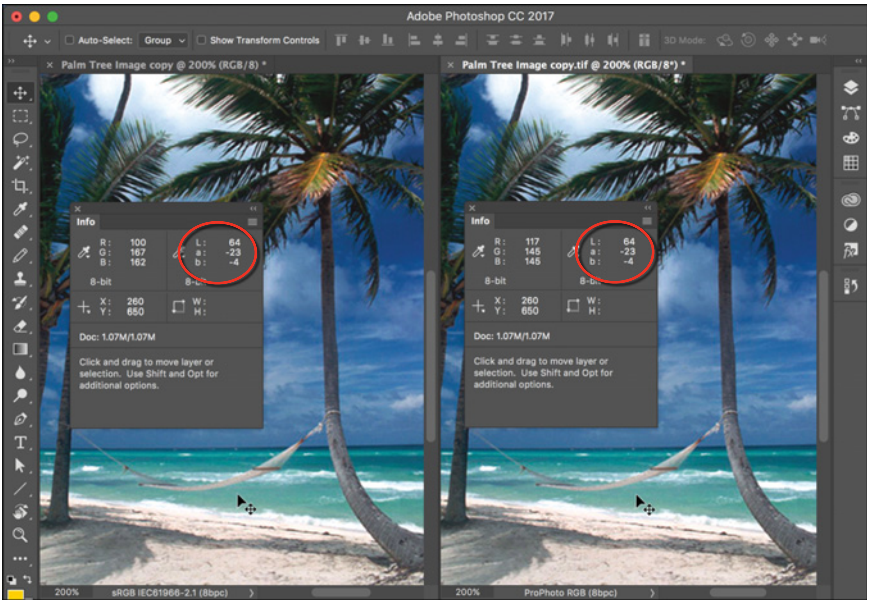
the source and destination devices. Generally, it is acceptable to have this item turned on. The ***Use Dither*** option is used for photographic images, dither should be on to preserve image quality. For test targets and calibration images, dither should be off to give exact values and make all values come out the same (no randomness). Comic book illustrations that rely on solid values should also disable the ***Use Dither*** option.

Preview. With ***Preview*** selected you can preview the effect of the color conversion. Image colors will often change due to gamut limitations of the chosen destination, and it is not always obvious, for example, whether perceptual or relative colorimetric rendering should be used, so ***Preview*** is a good way to see which one works for you.

Usually the output print process (or RIP) will do an equivalent of ***Convert to Profile***, but a user may want to do the conversion themselves and then turn off color management in the RIP or printing process. The advantage of doing the color conversion yourself (using ***Convert to Profile***) is that you are sure which profile is being used as the source and destination, and you are able to select the rendering intent and the CMM to be used.

Convert to Profile changes the RGB pixel values in an image, but tries not to change the color appearance, Figure 11.12. Using ***Convert to Profile*** from sRGB to ProPhoto RGB has changed the RGB pixel values. We may interpret this result as: "what pixel values do I need to create the same color, but on a different device?" In doing a conversion from one color space to another, the L*a*b* value of a pixel stays the same.

A color space conversion is also possible via another dialog called ***Image>Mode>CMYK Color***. ***Convert to Profile*** and a mode change using ***Image>Mode>CMYK Color*** are the same process, but Convert to Profile is preferable as it shows us which



Adobe Photoshop CC 2017
Auto-Select: Group
Show Transform Controls
3D Mode:
Palm Tree Image copy @ 200% (RGB/8) *
Palm Tree Image copy.tif @ 200% (RGB/8*) *
Info
200%
sRGB IEC61966-2.1 (8bpc)
ProPhoto RGB (8bpc)

R: 100 G: 167 B: 162
L: 64 a: -23 b: -4
8-bit
X: 260 Y: 650
W: H:
Doc: 1.07M/1.07M
Click and drag to move layer or selection. Use Shift and Opt for additional options.

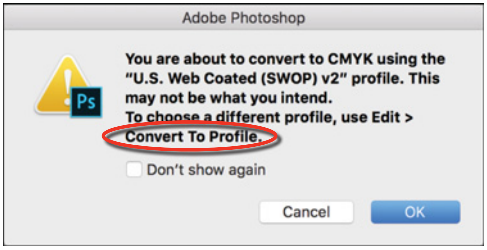
R: 117 G: 145 B: 145
L: 64 a: -23 b: -4
8-bit
X: 260 Y: 650
W: H:
Doc: 1.07M/1.07M
Click and drag to move layer or selection. Use Shift and Opt for additional options.

Figure 11.12 When we use ***Convert to Profile***, the colors in the image do not change, note how the L*a*b* color remains the same.

profiles, rendering intents and settings are being used. If you have blind-faith and bravely use ***Image*>*Mode*>*CMYK Color***, Photoshop gently suggests using the safer ***Convert to Profile*** dialog, Figure 11.13.

11.5.6 Soft Proof Setup

Photoshop offers options that allow you to see a simulation of what the printed image will look like. If you want to proof your image, you can use Photoshop's ***View*>*Proof Setup*** menu, Figure 11.14. If you have an accurate monitor and printer profile, ***Proof Setup*** can give you a prediction of the printed result. What is more, you can edit the image if you see something you do not like. The ***Proof Setup*** menu creates a "soft proof," i.e. a realization on your monitor of the expected printed result. With a soft



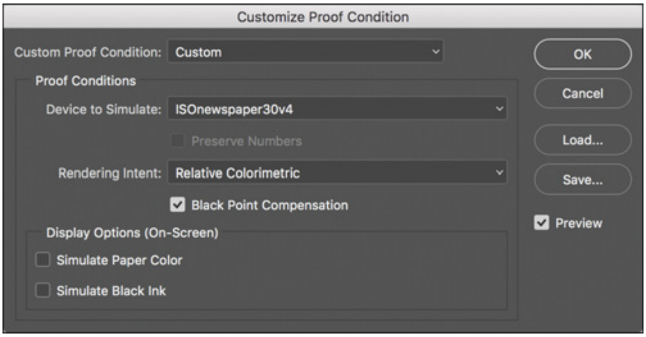
Adobe Photoshop

You are about to convert to CMYK using the "U.S. Web Coated (SWOP) v2" profile. This may not be what you intend.
To choose a different profile, use Edit > Convert To Profile.

☐ Don't show again

Cancel OK

Figure 11.13 If you use ***Image*>*Mode*** to do a color conversion, Photoshop correctly suggests it is better to use ***Convert To Profile***.


Customize Proof Condition

Custom Proof Condition: Custom

Proof Conditions

Device to Simulate: ISOnewspaper30v4

☐ Preserve Numbers

Rendering Intent: Relative Colorimetric

☑ Black Point Compensation

Display Options (On-Screen)

☐ Simulate Paper Color

☐ Simulate Black Ink

☑ Preview

Figure 11.14 The Proof Setup>Customize Proof Condition allows you to choose a press for soft proofing.

proof you do not have to print the image to realize something is wrong, so soft proofing can provide considerable savings in time and materials. *Importantly for this discussion,* ***View>Proof Setup*** *is a safe, simulated operation that does not change your image data.*

Proof Setup allows you to select a device to simulate, i.e. any output process. By choosing different output profiles we can see what an image will look like on different print processes, such as coated vs. uncoated paper; newsprint vs. glossy paper, or on two different desktop printers. The title bar of the image window shows what is happening, and which profiles are being used – the image is originally in RGB, Figure 11.15a. The image can be viewed in SWOP CMYK, Figure 11.15b. It is possible to stain the colors that are out of gamut and are going to be changed, Figure 11.15c. The appearance of the image to a color deficient observer can also be simulated, Figure 11.15d.

One way to use ***Proof Setup*** is to make a number of copies on screen using ***Image>Duplicate*** and then select various printer profiles (via ***View>Proof Setup>Custom***), and preview the image (via ***View>Proof Colors***). By choosing different output profiles, we can see what an image will look like on different print processes.

11.6 Photoshop and Printing

The final place where we can apply color management in Photoshop is during printing. It is interesting to note that we must manage color during printing and in fact there is no option, despite numerous user requests, to print from Photoshop with no color management. (No color management is needed, for example, when printing a test chart.)

11.6.1 Photoshop's Print Settings

To print from Photoshop, we use ***File>Print***, which launches the ***Print Settings*** dialog with two main color management options – ***Printer Manages Color*** or ***Photoshop Manages Color***, Figure 11.16. This dialog makes it very clear where the color

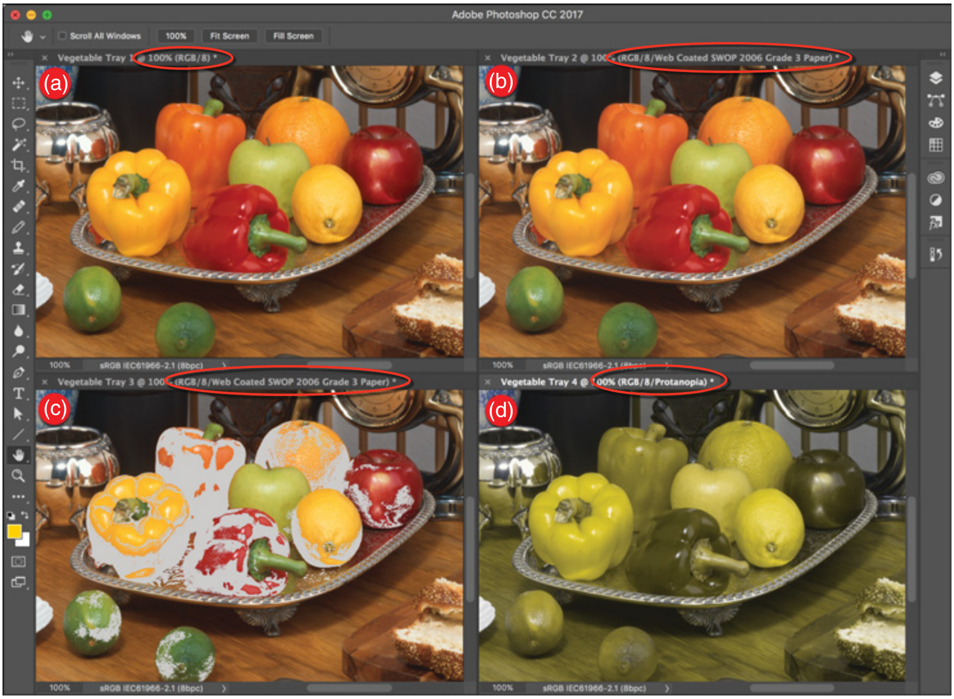
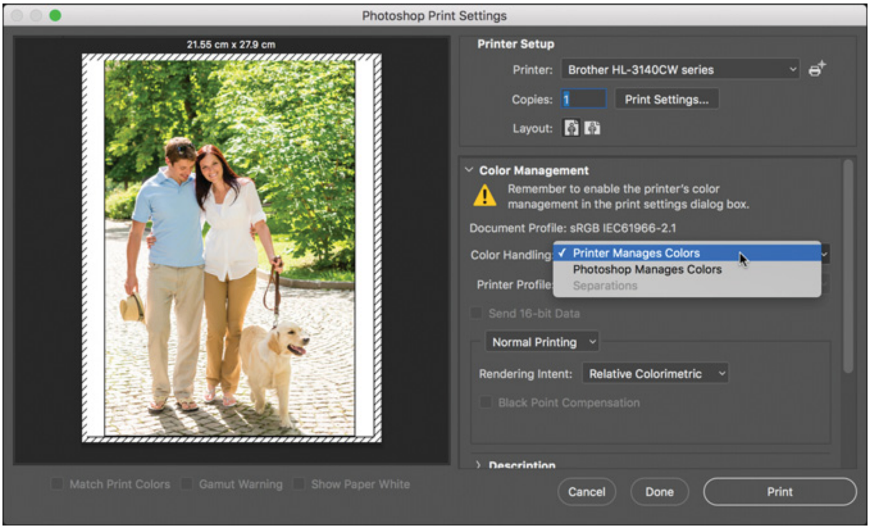

Adobe Photoshop CC 2017
Scroll All Windows
100%
Fit Screen
Fill Screen
Vegetable Tray 1 @ 100% (RGB/8) *
Vegetable Tray 2 @ 100% (RGB/8/Web Coated SWOP 2006 Grade 3 Paper) *
Vegetable Tray 3 @ 100% (RGB/8/Web Coated SWOP 2006 Grade 3 Paper) *
Vegetable Tray 4 @ 100% (RGB/8/Protanopia) *
(a)
(b)
(c)
(d)
100%
sRGB IEC61966-2.1 (8bpc)

Figure 11.15 (a) is an original RGB image, (b) is a simulation of the image colors on a SWOP CMYK printing press using ***View>Proof Setup***, (c) is a gamut stain, using ***View>Gamut Warning*** indicating which parts of the image are out of the print gamut, (d) is what the image would like to a red-green color deficient observer.


Photoshop Print Settings

21.55 cm x 27.9 cm

Printer Setup

Printer: Brother HL-3140CW series

Copies: 1

Color Management

Remember to enable the printer's color management in the print settings dialog box.

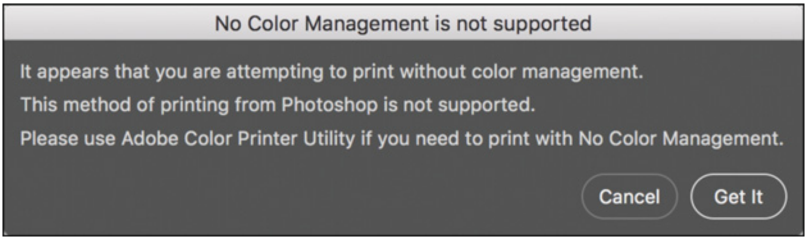
Document Profile: sRGB IEC61966-2.1

Color Handling: ✓ Printer Manages Colors

Rendering Intent: Relative Colorimetric

Print Settings...
Layout:
Photoshop Manages Colors
Separations
Printer Profile:
☐ Send 16-bit Data
Normal Printing
☐ Black Point Compensation
Description
☐ Match Print Colors
☐ Gamut Warning
☐ Show Paper White
Cancel
Done
Print

Figure 11.16 When printing, it is possible to select ***Printer Manages Color***, or ***Photoshop Manages Color***, which makes it very clear where color management is being done. Image licensed by Ingram Image.



No Color Management is not supported

It appears that you are attempting to print without color management.
This method of printing from Photoshop is not supported.
Please use Adobe Color Printer Utility if you need to print with No Color Management.

Figure 11.17 Photoshop displays this confusing dialog when the image's source and destination profile is the same. The user would have been trying to print to a printer with "No Color Management."

management is being done, as we would like to perform color management in Photoshop or the printer, but not both. If the ***Printer Manages Color*** then we gray out options in Photoshop; when ***Photoshop Manages Color***, we turn off color management in the printer.

When the ***Printer Manages Color***, color management is not done by Photoshop, and the image is handed to the printer. Control of color is relegated to the printer driver or RIP, and the user configures the color conversion settings in a printer dialog.

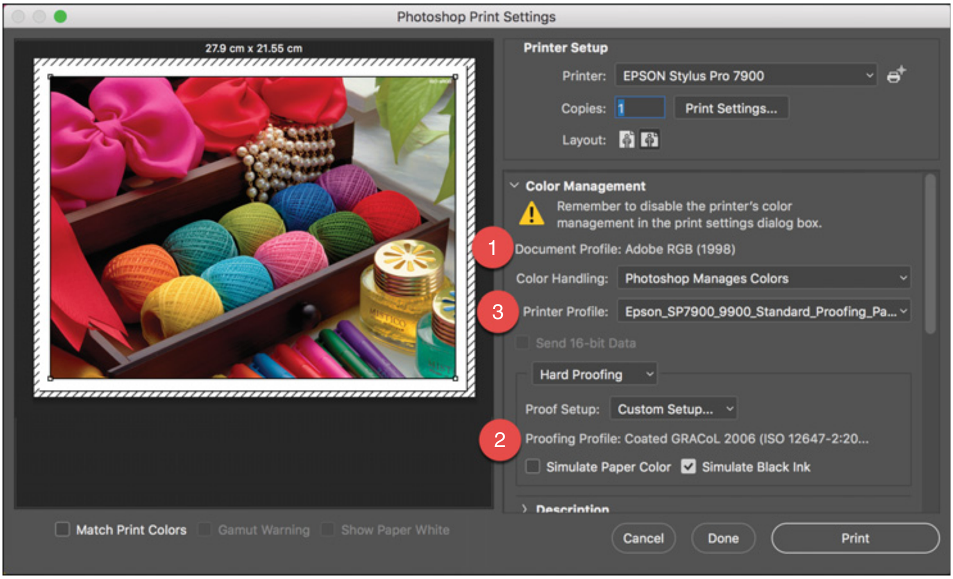
Using ***Photoshop Manages Colors*** is the preferred setting as we can clearly configure the settings for source and destination profiles, rendering intent, the CMM, and Photoshop's color management is robust and coherent. When Photoshop manages colors, the image data is processed via the input profile and the printer profile and sent to the printer. Note that the original is left unchanged, which is a good thing. When printing in this mode we would not like the printer to to do any additional color management and therefore, color management in the printer driver should be turned off.

To print a test chart it is necessary to find a way to print with "no color management." One trick is to assign the printer profile to the image. In color management, whenever the input and output profile is the same, the color management system realizes there is nothing to do and so does nothing. So one way to turn off color management is to set the source and destination profiles to be the same. Even this workaround is detected and disallowed in Photoshop CC, Figure 11.17.

11.6.2 Hard Proofing

The Print Settings dialog has a menu item for Hard Proofing, Figure 11.18. Hard proofing is, for example, where we simulate on an inkjet printer a semblance of what the colors in the image would look like if printed on a printing press. We may seek to simulate, for example, a GRACoL press result on a local Epson Stylus Pro 7900 inkjet proofer in order to show the customer a physical proof.

A hardcopy press proof requires three profiles, their selection in Photoshop is shown in Figure 11.18. Profile #1 is the source profile for the image, called Document Profile in Photoshop. Profile #2 is the press characteristics we seek to represent. This may be an actual press profile, or more commonly a reference printing condition, such as GRACoL or SWOP. Finally, Profile #3 is the local proofer profile and this profile is used to create an accurate proof on the inkjet proofer. By using this sequence of profiles image data is converted into the smaller press color space, and then those smaller range of



Printer: EPSON Stylus Pro 7900

Copies: 1

Remember to disable the printer's color management in the print settings dialog box.

Document Profile: Adobe RGB (1998)

Color Handling: Photoshop Manages Colors

Printer Profile: Epson_SP7900_9900_Standard_Proofing_Pa...

☐ Send 16-bit Data

Proof Setup: Custom Setup...

Proofing Profile: Coated GRACoL 2006 (ISO 12647-2:20...

☐ Simulate Paper Color ☑ Simulate Black Ink

☐ Match Print Colors ☐ Gamut Warning ☐ Show Paper White

Figure 11.18 Photoshop has a powerful Hard Proofing option that is used to create a simulation of the press output on an inkjet proofer. In press proofing, three profiles are used, as described in the text.

colors are color managed using the proofer profile to accurately print them on an inkjet device.

11.7 Putting It All Together

If you have profiling hardware and software and a copy of Photoshop you are ready to implement a color-managed system. Let us use Photoshop to bring together a number of device profiles to process, view, and print an image.

This section provides a summary of the steps involved in creating a color-managed system to evaluate an original and a reproduction and to conduct a screen-to-print match. The steps incorporate many of the concepts developed in earlier chapters and a number of Photoshop settings discussed in this chapter. These are only general guidelines, and each user is likely to have specific requirements that will involve customizing these procedures for their local environment.

- First, acquire an image with a digital camera. You can use Adobe Camera Raw within Photoshop to open a RAW format file, or you can accept JPEG images from your camera. In either case pay attention and honor the profile associated with your image – the profile may typically be sRGB, Adobe RGB, ProPhoto RGB, etc.
- Control your viewing environment. Dim room lights. Use a viewing booth with adjustable color temperature and light levels. Avoid rooms with direct daylight.
- Profile your monitor. Use a measuring instrument-based program to profile your monitor. Choose a reasonable white point and gamma, perhaps D65 and 2.2.

- Check that the monitor profile is the one you want to use. Go to ***System Preferences*** and ensure that the monitor profile you want is listed and selected.
- Profile your printer. Linearize/calibrate your printer. Print a test chart. Ensure that no color management is being used during printing. Measure the chart and make a profile. Choose appropriate black generation settings and choose the maximum profile quality setting.
- An alternative to profiling your printer is to use recommended media in the printer and the associated profile within Photoshop. You may use, for example, Premium Glossy Photo paper in your Epson Stylus Pro 3880 printer with photo black ink and print mode of 2880 dpi, and therefore select the provided profile – "SP3880 2880 Premium Glossy Photo PK.icc"
- Place the camera, and printer profiles in the correct location in the system folder. Profiles that individual users want to have exclusively for themselves should be installed in the User Library. Profiles to be accessed by multiple users sharing the same machine should be stored in the System Library
- Launch Photoshop. In ***Photoshop>Edit>Color Settings***, select ***Color Management Policies RGB: Preserve Embedded Profiles and Profile Mismatches: Ask When Opening***. Open the digital camera images and use the ***Missing Profile*** or ***Embedded Profile Mismatch*** dialogs to ensure you have retained your camera profile.
- Ensure that the bottom left corner of Photoshop's image window shows the correct profile name. If the profile is not correct, use ***Photoshop>Edit>Assign Profile*** to assign the source profile to the image.
- Color accurate viewing. The screen image now shows a color-managed version of the image.
- Color accurate printing. Choose File>Print. For the Document Profile, make sure the camera profile is shown. Select ***Photoshop Manages Colors*** and choose the printer profile that was supplied or made earlier. Ensure that the printer is using the materials and settings that were used when the profiling test chart was printed (or if you are using a vendor supplied profile, then the media in the printer and the printer settings correspond to the chosen printer profile). Turn off color management in the printer. Print the image.
- To ensure a color match, make sure the Conversion Options in ***Edit>Color Settings*** are not set to Perceptual or Saturation rendering intent.
- Screen to print match. Place the print you have just made in a viewing booth near the monitor, as shown in Figure 11.19. Size the image on the screen to match the printed image. In Photoshop select ***View>Proof Setup>Custom*** and select the printer profile you used earlier. The printed image and the monitor image will be a close match.
- Hardcopy press proof. In Photoshop select ***File>Print*** and in ***Color Management***, select ***Hard Proofing***. Identify a sequence of three profiles that create on an inkjet proofer, a simulation of the press result. This is a color accurate hardcopy press proof, also called a "contract color proof".

The process just described is a generalization, and different users will have different conditions and specific tolerances. Further, the lighting, quality of the profile, and gamut of the image all need to be considered. Nevertheless, the preceding sequence covers the main parameters of using Photoshop to establish the most commonly used practical color management operations.

Figure 11.19 If you have a profile for your camera, monitor, and printer then you can use Photoshop to compare the screen image to a printed image in a light booth.

11.8 Summary

Photoshop is by far the most important application for end-user implementation of a color-managed system. This chapter explored color management within Photoshop CC 2017, though the principles and concepts are applicable to most recent versions of the program.

A brief historical review was presented, and it was noted that much earlier shortcomings of Photoshop's "enforced" workflows are a thing of the past and all versions of Photoshop now employ a stable, correct, color management architecture.

Three rules were identified that apply to color management in general and to Photoshop in particular. Rule #1 is that every image must have a profile. Rule #2 is that all conversions need at least two profiles, a source and a destination profile. Rule #3 seeks to minimize color conversions and to use simulations wherever possible.

The Working Space, how it is used, and its advantages and disadvantages were described. It was noted the North American default setting is extremely dated and limiting in terms of color management.

Color management in Photoshop is spread throughout the interface. A number of menus were described. These related to ***File>Open***, ***Assign Profile***, ***Convert to Profile***, ***Color Settings***, ***Proof Setup***, and ***Print***.

It was shown that many of Photoshop's color conversions could be done for real, or in simulation mode without altering the original image. In this regard ***View>Proof Setup*** is a powerful, time saving, and accurate (but under-utilized) tool.

The ***Print Settings*** dialog allows us to print a color-managed image using either Photoshop's color processing or by handing off the image to the printer driver or RIP. The ***Print Settings*** dialog also allows us to easily obtain a hard proof (press proof) of any selected press condition.

This chapter ended with a step-by-step process that showed how profiles could be used in Photoshop to create workflows that explored the immense capabilities of an ICC workflow, including color-accurate viewing and editing, soft proofing, and press proof.

Adobe Photoshop is an indispensable tool for creating and managing color work, and also as a benchmark against which to compare the results of color conversions in other programs.

A

Appendix

The color process used to print this book, can be evaluated by measurement of the 2-row IDEAlliance ISO 12647-7 Digital Control Strip, Figure A.1. This control strip consists of 54 known CMYK patches, arranged in two rows of 27 patches each.

The size of a page in the printed book may not accommodate the control strip at 1 : 1 size, causing it to be reduced to fit on the page. This will create patches that are too small to be measured by commercial scanning instruments. The interested reader can measure each patch in spot mode, or consider Figure A.2.

In order to facilitate scanning in strip mode, the control strip values have been formatted and provided in an image that is 17.5 × 5.9 cm, Figure A.2. It is important that the target is reproduced at actual size. The provided format can be measured with X-Rite i1Profiler software and an X-Rite i1Pro2 spectrophotometer.

The CMYK patch values are provided in Table A.1.

The chart in Figure A.1 or Figure A.2 can be removed from the book and measured in terms of L*a*b*. Duplicate pages are provided for this purpose. The L*a*b* measurement values can be compared to any reference printing condition, e.g. FOGRA51, GRACoL, CRPC 6, to understand the color characteristics of the print process. This experiment demonstrates the practical application of color management and the process of "printing to the numbers".

Understanding Color Management, Second Edition. Abhay Sharma.
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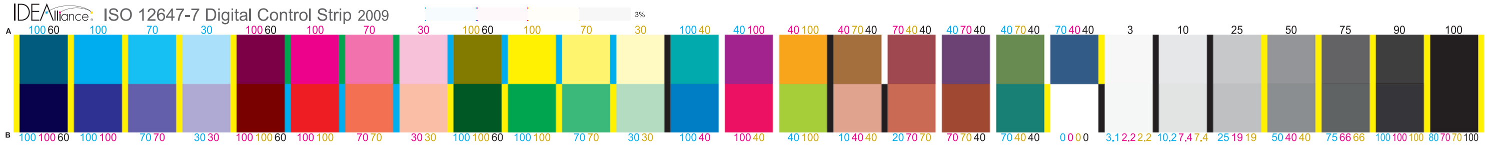
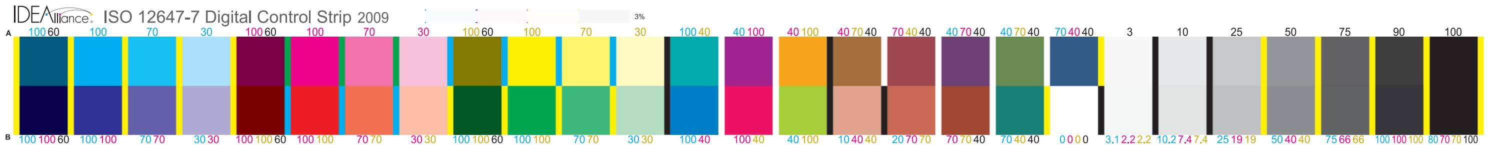

IDEAlliance ISO 12647-7 Digital Control Strip 2009
3%
A
100 60
100
70
30
100 60
100
70
30
100 60
100
70
30
100 40
40 100
40 100
40 70 40
70 40 40
40 70 40
40 70 40
70 40 40
3
10
25
50
75
90
100
B
100 100 60
100 100
70 70
30 30
100 100 60
100 100
70 70
30 30
100 100 60
100 100
70 70
30 30
100 40
100 40
40 100
10 40 40
20 70 70
70 70 40
70 40 40
0 0 0 0
3,1 2,2 2,2
10,2 7,4 7,4
25 19 19
50 40 40
75 66 66
100 100 100
80 70 70 100

Figure A.1 The 2-row IDEAlliance ISO 12647-7 Digital Control Strip contains 54 CMYK patches.


IDEAlliance ISO 12647-7 Digital Control Strip 2009
3%
A
100 60
100
70
30
100 60
100
70
30
100 60
100
70
30
100 40
40 100
40 100
40 70 40
70 40 40
40 70 40
40 70 40
70 40 40
3
10
25
50
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B
100 100 60
100 100
70 70
30 30
100 100 60
100 100
70 70
30 30
100 100 60
100 100
70 70
30 30
100 40
100 40
40 100
10 40 40
20 70 70
70 70 40
70 40 40
0 0 0 0
3.1 2.2 2.2
10.2 7.4 7.4
25 19 19
50 40 40
75 66 66
100 100 100
80 70 70 100

Figure A.1 The 2-row IDEAlliance ISO 12647-7 Digital Control Strip contains 54 CMYK patches.

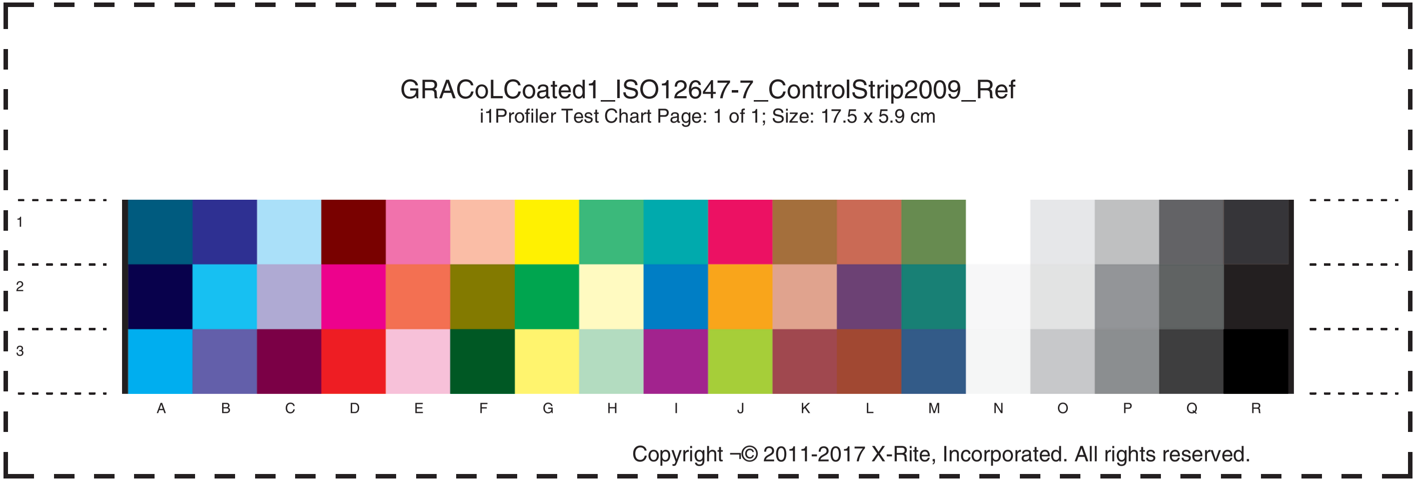
GRACoLCoated1_ISO12647-7_ControlStrip2009_Ref
i1Profiler Test Chart Page: 1 of 1; Size: 17.5 x 5.9 cm
1
2
3
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
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Figure A.2 This chart can be removed from the book and measured using X-Rite i1Profiler software and an X-Rite i1Pro2 spectrophotometer.

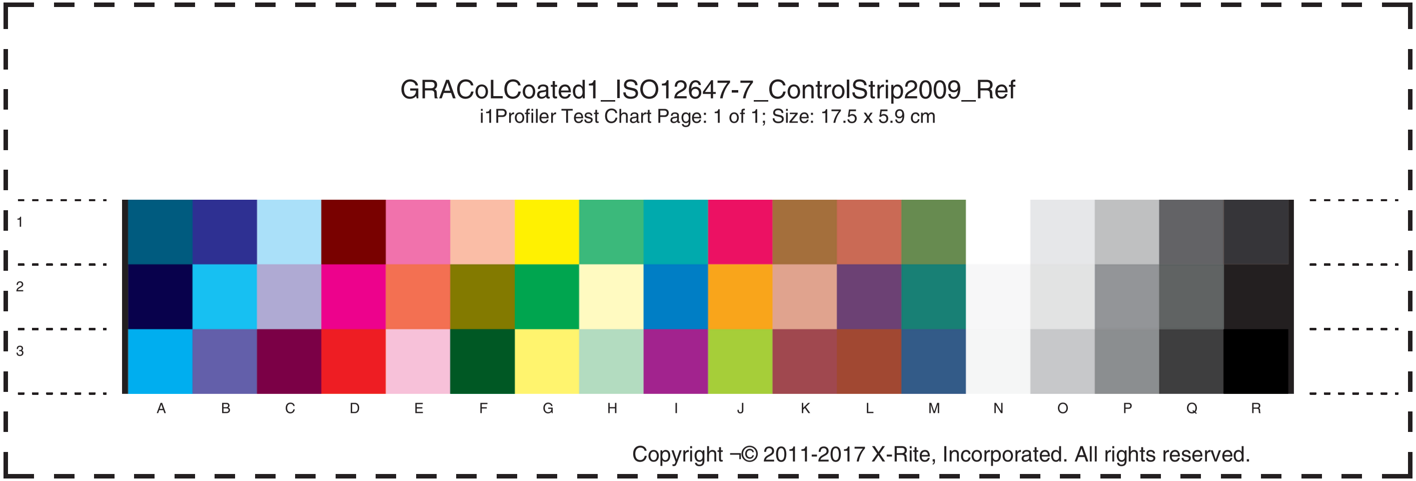
GRACoLCoated1_ISO12647-7_ControlStrip2009_Ref
i1Profiler Test Chart Page: 1 of 1; Size: 17.5 x 5.9 cm
1
2
3
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
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Figure A.2 This chart can be removed from the book and measured using X-Rite i1Profiler software and an X-Rite i1Pro2 spectrophotometer.

Table A.1 The IDEAlliance 12647-7 Digital Control Strip 2009 patch ID and CMYK values

Patch ID	C	M	Y	K
A1	100	0	0	60
B1	100	100	0	60
A2	100	0	0	0
B2	100	100	0	0
A3	70	0	0	0
B3	70	70	0	0
A4	30	0	0	0
B4	30	30	0	0
A5	0	100	0	60
B5	0	100	100	60
A6	0	100	0	0
B6	0	100	100	0
A7	0	70	0	0
B7	0	70	70	0
A8	0	30	0	0
B8	0	30	30	0
A9	0	0	100	60
B9	100	0	100	60
A10	0	0	100	0
B10	100	0	100	0
A11	0	0	70	0
B11	70	0	70	0
A12	0	0	30	0
B12	30	0	30	0
A13	100	0	40	0
B13	100	40	0	0
A14	40	100	0	0
B14	0	100	40	0
A15	0	40	100	0
B15	40	0	100	0
A16	0	40	70	40
B16	10	40	40	0
A17	0	70	40	40
B17	20	70	70	0
A18	40	70	0	40
B18	0	70	70	40

Table A.1 (*Continued*)

Patch ID	C	M	Y	K
A19	40	0	70	40
B19	70	0	40	40
A20	70	40	0	40
B20	0	0	0	0
A21	0	0	0	3
B21	3.1	2.2	2.2	0
A22	0	0	0	10
B22	10.2	7.4	7.4	0
A23	0	0	0	25
B23	25	19	19	0
A24	0	0	0	50
B24	50	40	40	0
A25	0	0	0	75
B25	75	66	66	0
A26	0	0	0	90
B26	100	100	100	0
A27	0	0	0	100
B27	80	70	70	100

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